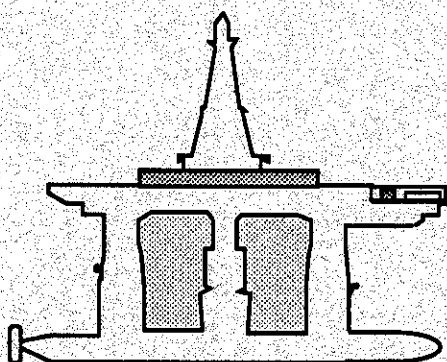


# **Development and Verification of a Computer Simulation Model for Evaluation of Siting Strategies for Mobile Drilling Units in Hurricanes**

**Report to  
U.S. Minerals Management Service  
Offshore Technology & Research Branch  
Herndon, Virginia**



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## **Chapter 1. Introduction and Background**

The purpose of this study is to develop and verify an analytical model for semi-submersible Mobile Offshore Drilling Units (MODUs) loading and movements in hurricanes.

In September 1992, hurricane Andrew swept through the eastern portion of the Gulf of Mexico(GOM) . Five MODUs both experienced damage and inflicted significant damage on surrounding facilities. The Zane Barnes, Zapata Saratoga, and Treasure 75 all moved very significant distance during hurricane Andrew. The storm snapped seven of the semi-submersible drilling unit Saratoga's eight anchor chains and drove the unit some 100 miles to the north until it collided with several platforms. The Zane Barnes broke loose from its eight anchors, drifted northwest some 30 miles, repeatedly colliding with several platforms and many pipelines. The anchors from the Treasure 75 reportedly collided with several platforms. The LOOP (Louisiana Offshore Oil Port) 36 inch diameter pipeline narrowly missed being snagged by the dragging anchors of one of these MODUs.

This is not the first hurricane in which there has been such damage. The destruction of the West Delta Block 134A platform by the semi-submersible drilling unit "Blue Water I" during hurricane Bestsy is one of the most notable of these earlier experiences. During the approach of hurricane Betsy, the Blue Water I semi-submersible drilling unit broke loose from its mooring and driven by the strong winds and currents the unit drifted some 25 miles to the until it collided with the industry's first platform installed in a water depth greater than 300 feet. Portions of the blue water drilling unit were found inside the destroyed platform.

This implies that there are fundamental issues need to be resolved regarding the policies and guidelines for manning, positioning and mooring semi-submersible drilling units in the GOM

during hurricane season. Special mooring areas and mooring systems have been proposed for MODUs operation during hurricane seasons.

The objective of this study is to develop an analytical model to evaluate MODUs movements in response to the combined load effect due to hurricane winds, waves and currents, then use a Monte-Carlo simulation process to evaluate the probability of collision between the MODU and large facilities.

The model is based on: 1) available statistics and hindcast results for hurricanes in the Gulf of Mexico since the turn of the century; 2) numerical models of wind, wave, current and their load effect on a platform; and 3) probability models to include the hurricane parameter variability, hurricane model uncertainties, and the spatial geometry. The input of the model is:

- 1) The location of the MODU and large facilities, e.g.,  $(X_M, Y_M)$  and  $(X_F, Y_F)$ ;
- 2) MODU parameters, e.g., displacement, draft, and mooring system capacity;
- 3) Hurricane parameters, e.g.,  $\Delta P, V_F, R_M$ ;
- 4) Hurricane direction parameters, e.g.,  $X_0, \varphi$ .

The output of the model is the probability of collision between the MODU and large facilities during the considered time period.

An application of the simulation model to the "Zane Barnes" moving in hurricane Andrew and the influence of different mooring strength and moored place to the probability of collision with large facilities are presented.

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## **Chapter 2. Hurricane History and Hindcast Parameters**

### **2.1 Hurricane Statistics**

The characteristics of past hurricanes in the Gulf of Mexico along the coastal area of Texas and Louisiana since the turn-of-the-century are summarized in Table 1. The parameters of most interest are the pressure difference ( $\Delta P$ ), radius of maximum wind speed( $R$ ), and storm translation speed ( $V_t$ ). The table values represent the maximum values observed when the storm crossed the shelf. Only storms with  $R$  less than 100 nm (nautical mile) are considered.

The first two moments of the hurricane parameters, i.e., their mean values, standard deviations, coefficient of variation and the correlation matrix are summarized in Table 2.

### **2.2 Storm Track and Occurrence Statistics**

On the basis of the statistical test by Ward. et al.[1978] and Bea [1975], the hurricane track shelf edge crossings are assumed to be uniformly distributed. The hurricane track directions are assumed to follow a triangular distribution. The peak value is 101 degrees relate to the coast line orientation according to Reference [8].

Previous investigations(e.g., Haring and Heideman, 1978) have shown that the occurrence of hurricanes over time can be approximately modeled as a simple Poisson Process (Bea 1975). The mean occurrence rate per time is, therefore, the only parameter required of the occurrence in a specified region. From Ward, et al. (1978), the occurrence rates for hurricanes in the Gulf of Mexico regions A, B, C, D in Fig. 2.1 are respectively 0.459, 0.563, 0.587, and 0.563 per year. As the widths of the regions are 360 nautical miles, the hurricane occurrence

statistics may alternatively be described by the mean rate of the storm tracks crossing the 600ft. depth contour line per year per nautical mile. For example, the occurrence rates at a point in region A, B, C, and D are correspondingly 0.00127, 0.00156, 0.00163, and 0.00156/year-nautical mile. Interpolation may be used to determine the occurrence rate at any given location on the contour line.

### **2.3. Hurricane Parameter Distributions**

The parameters of most interest are  $\Delta P$ ,  $R$  and  $V_f$ . Since these three important hurricane parameters are correlated, they are modeled as jointly log-normal random variables with parameters given in Table 3. In other words, the logarithmic transforms of these parameters follow a jointly normal distribution.

It is pointed out that the log normal distribution has been used in almost all previous risk studies of hurricanes(e.g., Batts, et al., 1980; Russell, 1968). It is a convenient model to use, in particular, in treating correlated random quantities.

# Table 1 Hurricane Statistics

110 Storms represented

| NO | STORM DATA | NAME   | DP(mb) | RM(nm) | VF(kts) |
|----|------------|--------|--------|--------|---------|
| 1  | 9/6/00     |        | 76     | 14     | 10      |
| 2  | 8/13/01    |        | 40     | 33     | 5       |
| 3  | 10/8/02    |        | 19     | 37     | 8       |
| 4  | 9/25/06    |        | 78     | 43     | 8       |
| 5  | 7/13/09    |        | 60     | 20     | 10      |
| 6  | 9/18/09    |        | 33     | 22     | 8       |
| 7  | 8/15/15    |        | 63     | 29     | 12      |
| 8  | 9/28/15    |        | 78     | 31     | 12      |
| 9  | 7/4/16     |        | 50     | 30     | 14      |
| 10 | 8/17/16    |        | 62     | 25     | 18      |
| 11 | 10/17/16   |        | 49     | 19     | 10      |
| 12 | 9/26/17    |        | 48     | 40     | 8       |
| 13 | 8/5/18     |        | 53     | 20     | 15      |
| 14 | 9/11/19    |        | 64     | 20     | 10      |
| 15 | 9/12/19    |        | 66     | 19     | 10      |
| 16 | 9/20/20    |        | 33     | 28     | 15      |
| 17 | 6/20/21    |        | 64     | 17     | 7       |
| 18 | 8/23/26    |        | 56     | 27     | 6       |
| 19 | 9/19/26    |        | 59     | 17     | 13      |
| 20 | 6/27/29    |        | 41     | 13     | 10      |
| 21 | 8/12/32    |        | 71     | 12     | 8       |
| 22 | 8/2/33     |        | 38     | 25     | 8       |
| 23 | 9/2/33     |        | 64     | 25     | 10      |
| 24 | 6/14/34    |        | 40     | 37     | 8       |
| 25 | 8/4/40     |        | 41     | 11     | 8       |
| 26 | 9/13/41    |        | 10     | 20     | 6       |
| 27 | 9/21/41    |        | 51     | 21     | 10      |
| 28 | 8/20/42    |        | 19     | 16     | 7       |
| 29 | 8/28/42    |        | 62     | 18     | 12      |
| 30 | 9/20/42    |        | 19     | 15     | 7       |
| 31 | 7/25/43    |        | 41     | 16     | 8       |
| 32 | 8/25/45    |        | 46     | 18     | 5       |
| 33 | 8/23/47    |        | 23     | 15     | 5       |
| 34 | 9/18/47    |        | 48     | 23     | 6       |
| 35 | 9/2/48     |        | 23     | 25     | 9       |
| 36 | 10/3/49    |        | 50     | 20     | 14      |
| 37 | 8/28/50    | Baker  | 25     | 21     | 12      |
| 38 | 9/23/56    | Flossy | 34     | 30     | 10      |
| 39 | 6/25/57    | Audrey | 62     | 19     | 14      |
| 40 | 8/8/57     | Bertha | 17     | 25     | 7       |
| 41 | 5/29/59    | Arlene | 14     | 50     | 5       |

| NO | STORM DATA | NAME     | DP(mb) | RM(nm) | VF(kts) |
|----|------------|----------|--------|--------|---------|
| 42 | 7/23/59    | Debra    | 32     | 28     | 3       |
| 43 | 9/14/60    | Ethel    | 43     | 18     | 11      |
| 44 | 9/8/61     | Carla    | 75     | 30     | 7       |
| 45 | 9/16/63    | Cindy    | 18     | 30     | 6       |
| 46 | 8/6/64     | Abby     | 16     | 15     | 9       |
| 47 | 10/1/64    | Hilda    | 73     | 21     | 6       |
| 48 | 9/9/65     | Betsy    | 72     | 40     | 17      |
| 49 | 8/18/67    | Beulah   | 62     | 25     | 8       |
| 50 | 6/23/68    | Candy    | 16     | 25     | 18      |
| 51 | 8/16/69    | Camille  | 105    | 12     | 14      |
| 52 | 8/1/70     | Celia    | 69     | 9      | 14      |
| 53 | 9/14/70    | Felicia  | 15     | 25     | 17      |
| 54 | 9/6/71     | Fern     | 34     | 26     | 5       |
| 55 | 9/15/71    | Edith    | 36     | 27     | 15      |
| 56 | 9/3/73     | Della    | 23     | 55     | 10      |
| 57 | 9/6/74     | Carmen   | 76     | 15     | 10      |
| 58 | 9/22/75    | Eloise   | 60     | 28     | 17      |
| 59 | 8/30/77    | Anita    | 86     | 15     | 9       |
| 60 | 9/4/77     | Babe     | 17     | 45     | 8       |
| 61 | 7/30/78    | Amelia   | 9      | 50     | 5       |
| 62 | 7/10/79    | Bob      | 21     | 40     | 12      |
| 63 | 8/30/79    | Elena    | 9      | 60     | 8       |
| 64 | 9/11/79    | Frederic | 65     | 25     | 11      |
| 65 | 8/7/80     | Allen    | 77     | 12     | 10      |
| 66 | 9/4/80     | Danielle | 14     | 20     | 10      |
| 67 | 9/10/82    | Chris    | 17     | 25     | 7       |
| 68 | 8/16/83    | Alicia   | 50     | 20     | 7       |
| 69 | 8/27/83    | Barry    | 28     | 15     | 10      |
| 70 | 9/8/84     | Diana    | 46     | 27.5   | 7       |
| 71 | 8/12/85    | Danny    | 28     | 36.5   | 12      |
| 72 | 8/27/85    | Elena    | 51     | 25     | 16      |
| 73 | 9/16/85    | Gloria   | 66     | 17.5   | 20      |
| 74 | 10/25/85   | Juan     | 32     | 34.5   | 8       |
| 75 | 11/15/85   | Kate     | 40     | 30.5   | 16      |
| 76 | 6/24/86    | Bonnie   | 21     | 40     | 8       |
| 77 | 8/14/86    | Charley  | 28     | 36.5   | 10      |
| 78 | 9/20/87    | Emily    | 56     | 22.5   | 18      |
| 79 | 10/9/87    | Floyd    | 20     | 40.5   | 10      |
| 80 | 9/1/88     | Debby    | 24     | 38.5   | 8       |
| 81 | 9/2/88     | Ernesto  | 20     | 40.5   | 25      |
| 82 | 9/7/88     | Florance | 40     | 30.5   | 14      |
| 83 | 9/8/88     | Gilbert  | 56     | 22.5   | 18      |
| 84 | 9/19/88    | Helene   | 76     | 12.5   | 10      |
| 85 | 10/10/88   | Joan     | 76     | 12.5   | 12      |
| 86 | 11/17/88   | Kelth    | 50     | 25.5   | 16      |
| 87 | 7/30/89    | Dean     | 32     | 34.5   | 20      |
| 88 | 8/2/89     | Chantal  | 26     | 37.5   | 10      |

| NO  | STORM DATA | NAME     | DP(mb) | RM(nm) | VF(kts) |
|-----|------------|----------|--------|--------|---------|
| 89  | 8/17/89    | Erin     | 40     | 30.5   | 18      |
| 90  | 8/30/89    | Gabriell | 76     | 12.5   | 20      |
| 91  | 10/12/89   | Jerry    | 30     | 35.5   | 12      |
| 92  | 7/24/90    | Bertha   | 40     | 30.5   | 12      |
| 93  | 8/4/90     | Diana    | 40     | 30.5   | 14      |
| 94  | 8/24/90    | Gustav   | 48     | 26.5   | 10      |
| 95  | 9/3/90     | Isidore  | 38     | 31.5   | 16      |
| 96  | 10/3/90    | Klaus    | 20     | 40.5   | 8       |
| 97  | 10/6/90    | Lili     | 28     | 36.5   | 8       |
| 98  | 10/9/90    | Marco    | 22     | 39.5   | 12      |
| 99  | 10/15/90   | Nana     | 22     | 39.5   | 8       |
| 100 | 8/16/91    | Bob      | 48     | 26.5   | 15      |
| 101 | 9/5/91     | Claudett | 70     | 15.5   | 12      |
| 102 | 10/25/91   | Grace    | 40     | 30.5   | 10      |
| 103 | 9/6/92     | Iniki    | 68     | 16.5   | 14      |
| 104 | 9/24/92    | Charley  | 40     | 30.5   | 8       |
| 105 | 10/28/91   | Unnamed  | 30     | 35.5   | 22      |
| 106 | 9/26/92    | Earl     | 20     | 40.5   | 12      |
| 107 | 10/22/92   | Frances  | 34     | 33.5   | 22      |
| 108 | 8/22/93    | Emily    | 46     | 27.5   | 10      |
| 109 | 9/7/93     | Floyd    | 32     | 34.5   | 25      |
| 110 | 9/18/93    | Harvey   | 26     | 37.5   | 25      |

**Table 2 Moment Statistics**  
110 Storms Represented

Statistical Parameters

| Parameters      | Mean Value | Variance | Std Deviation | C.O.V. |
|-----------------|------------|----------|---------------|--------|
| $\Delta P$ (mb) | 43.2       | 431.4    | 20.77         | 0.48   |
| R (nm)          | 26.9       | 104.1    | 10.2          | 0.37   |
| $V_f$           | 11.3       | 22.1     | 4.7           | 0.41   |

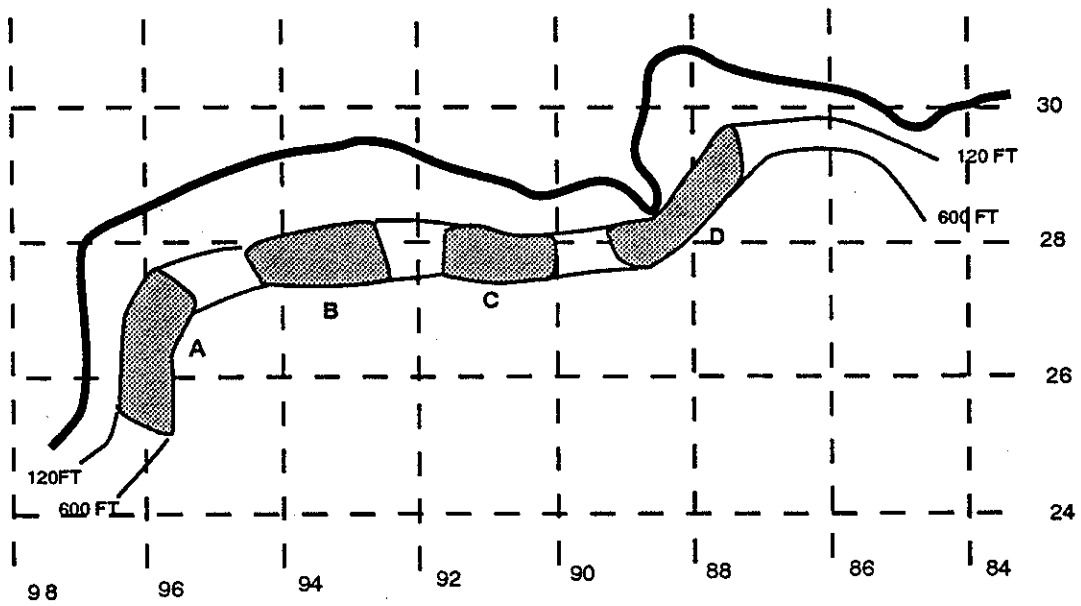
Correlation Coefficient Matrix

|                 | $\Delta P$ (mb) | R (nm) | $V_f$ |
|-----------------|-----------------|--------|-------|
| $\Delta P$ (mb) | 1.000           | -0.52  | 0.122 |
| R (nm)          | -0.52           | 1.000  | 0.022 |
| $V_f$           | 0.122           | 0.022  | 1.000 |

**Table 3****Hurricane Parameter Distribution**

76 Storms DP&gt;30mb

| <b>Parameter</b>    | <b><math>\Delta P</math> (mb)</b> | <b>R(nm)</b> | <b><math>V_f</math> (kts)</b> |
|---------------------|-----------------------------------|--------------|-------------------------------|
| <b>Sample Size</b>  | 76                                | 76           | 76                            |
| <b>Distribution</b> | Lognormal                         | Lognormal    | Lognormal                     |
| <b>Mean</b>         | 53.64                             | 24.16        | 11.8                          |
| <b>St. Dev.</b>     | 16.14                             | 7.85         | 4.5                           |
| <b>COV.</b>         | 0.3                               | 0.32         | 0.38                          |



**Fig. 2.1 Gulf Coastal Water Regions (Ward, et al., 1978)**



## Chapter 3. Hurricane Wave Heights and Return Period

### 3.1. Hurricane Models

The hurricane is assumed to be a storm traveling along a straight line with a given translation speed and direction. The wind field is governed primarily by the three parameters  $\Delta P$ ,  $R$  and  $V_f$  and the Coriolis force. The changes in the storm parameters after shelf edge crossing are not considered, i.e., the intensity of the hurricane is assumed to be stationary during passage over the continental shelf. The wind and wave field based on parametric expressions of more sophisticated numerical models. These parametric models which were provided by Reference[15] give the wind velocity, significant wave height, and wave direction as function of the hurricane parameters and the site position relative to the storm center. The current field is based on a one-dimensional numerical model which is a simplified version of the three-dimensional numerical model by Reference[15]. The models are briefly described in the following, details can be found in Cooper (1988).

#### 3.1.1 Wind Field

The wind speed (in m/s) and direction  $\beta$  (polar angle in degree ) as functions of the position relative to the storm center in polar coordinates  $r$  and  $\theta$  are given by

$$W = W_m (r / R)^a \quad \text{for} \quad r/R > 1 \quad (3.1)$$

$$W = 1.047 W_m [1 - \exp(-3.1r / R)] \quad \text{for} \quad r/R < 1 \quad (3.2)$$

in which

$$W_m = 0.885(5.6\sqrt{\Delta P} - 0.5Rf) + V_f \cos \theta \quad (3.3)$$

$$a = -0.38 + 0.08 \cos \theta \quad (3.4)$$

where,  $f$  = Coriolis parameter in rad/s,  $\Delta P$  in mb,  $V_f$  in m/s, and  $R$  in m

$$\beta_{wind} = \theta + \alpha + 90^\circ \quad (3.5)$$

in which  $\alpha$  is the deflection angle given by:

$$\alpha = 22 + 10 \cos \theta \quad (3.6)$$

### 3.1.2. Wave Field

The parametric model for significant wave height  $H_{sm}$ , at a given location can be expressed as a "25 percentile rule" or:

$$H_{sm} = 0.25 V_m \quad (3.7)$$

In which  $V_m$  is the local wind speed in m/s. The equation for the average wave direction  $\phi$  (polar angle in degree) is:

$$\phi = \alpha + a(r/R)^b + \theta - 90^\circ \quad (3.8)$$

in which

$$a = 144 + 39 \cos \theta - 25 \sin \theta - 15 \cos 2\theta \quad (3.9)$$

$$b = -0.08 \quad (3.10)$$

The r.m.s. errors are of the order of 10 to 20 degrees.

The equation for peak period,  $T_p$  (s), is:

$$T_p = aW^b \quad (3.11)$$

where,

$$a = 8.0 - 3.5 \cos \theta + 2.7 \sin \theta \quad (3.12)$$

$$b = 0.143 + 0.138 \cos \theta - 0.074 \sin \theta \quad (3.13)$$

### 3.1.3. Current Field

The following parametric model has been developed for the expected maximum current velocity ( $U_m$ , m/s, average velocity in upper 30-meter thick mixed layer), concurrent in time with the occurrence of the expected maximum wave:

$$U_m = \epsilon V_m \quad (3.14)$$

Where  $\epsilon = 0.02 - 0.03$ ,  $V_m$  is the 10m elevation, 10 minute average wind speed at the time that the cyclone crosses the site. The current direction is assumed the same as the wave direction.

### 3.1.4. Surge of Sea Surface

The surge of the sea surface due to hurricane in deep water is determined as:

$$\Delta h = 0.03H_{\max}. \quad (3.15)$$

where,  $H_{\max} = f(\Delta p)$ , is the maximum wave height due to the hurricane in deep water.

### 3.2. Expected Maximum Wave Heights, Given Significant Wave Heights

The expected maximum wave height,  $H_m$ , could be estimated from the short term wave height distribution based on 1000 waves (expressing a 3-hour duration of the maximum sea state intensity at the location):

$$H_m = \bar{\zeta} H_{sm} \sqrt{\frac{\ln N}{2}} \quad (3.16)$$

where  $\bar{\zeta} = 0.93$ ,  $V_{\zeta} = 8\%$

Thus, the expected maximum wave height could be estimated as:

$$H_m = 1.73 H_s \quad (3.17)$$

### 3.3 Shoaling Effect

Storm waves tend to be attenuated by a variety of processes as they propagate across the relatively shallow depths of the Texas and Louisiana Continental Shelves. As a wave

propagates from deep to shallow water, its height and length change. The transformed wave height,  $H$ , at shallow water depth relative to the original deep water wave height,  $H_0$ , can be computed from:

$$\frac{H}{H_0} = \left(\frac{V_0}{V}\right)^{\frac{1}{2}} \left(\frac{b_0}{b}\right)^{\frac{1}{2}} \quad (3.18)$$

Where  $V$  is the group velocity of the waves,  $b$  is the distance between pairs of adjacent wave rays, and the subscript  $0$  refers to deep water condition.

The term  $\left(\frac{V_0}{V}\right)^{\frac{1}{2}}$  is also known as the shoaling coefficient,  $K$ . The shoaling coefficient is given according to linear wave theory by

$$K' s = \left( \frac{1}{\left(1 + \frac{2kh}{\sinh 2kh}\right) \tanh kh} \right)^{\frac{1}{2}} \quad (3.19)$$

Where  $h$  is the water depth and  $k$  is the wave number. where,  $L = \frac{gT^2}{2\pi} \tanh\left(\frac{2\pi d}{L}\right)$

Eckart(1952) gives an approximate expression for equation (3.19), which is correct to within about 5 percent. This expression is given by:

$$L = \frac{gT^2}{2\pi} \sqrt{\tanh\left(\frac{4\pi^2 d}{T^2 g}\right)} \quad (3.20)$$

$$T = 2.7 \sqrt{H_{\text{meter}}} \quad (3.21)$$

$K$ 's is then given explicitly as a function of wave length and water depth.

The term  $\left(\frac{b_0}{b}\right)^{\frac{1}{2}}$  in the shoaling equation represents the relative spacing of adjacent wave rays and is also defined as the refraction coefficient,  $K_R$ . Physically, the relative spacing

between wave rays represents the local wave energy density. It is generally assumed that the wave energy contained between wave orthogonal is conserved as the wave front progresses. Various graphical and numerical methods are available to compute wave refraction. In this study, the graphical procedure was adopted. However, most of the wave paths were near normal to the smoothed depth contours; thus, the wave refraction effects proved to be insignificant.

The shoaling effect of the current is defined as [Reference(16)]:

$$U = (2.5 - \frac{1.5}{250}d)U_D \quad (3.22)$$

where  $U_D$  is the current velocity at 250ft depth of water (Fig. 3.1).

The shoaling effect of the surge of the sea surface is defined as:

$$\Delta h' = \Delta h \cdot k \quad (3.23)$$

where  $k$  is the shoaling effect parameter.

$$K = (1 + \frac{3(300 - h)}{290}) \quad (3.24)$$

and,  $\Delta h$  is the surge in deep water (300ft).

The wind velocity in shallow water is assumed the same as in deep water. (See Fig. 3.1)

### 3.4. Expected Maximum Wave Heights and Return Period

From the assumptions and the procedure above, the expected maximum deepwater (300ft) wave heights in Gulf of Mexico is:

$$H_m = C(\Delta P_m)^{\frac{1}{2}} \bar{\psi} \bar{\zeta} H_{sm} \sqrt{\frac{\ln N}{2}} \quad (3.25)$$

|       |                          |                       |
|-------|--------------------------|-----------------------|
| where | $\bar{C} = 4.4$          | $V_C = 6\%$           |
|       | $\bar{\psi} = 0.25$      | $V_\psi = 10\%$       |
|       | $\bar{\zeta} = 0.93$     | $V_\zeta = 8\%$       |
|       | $\bar{\Delta P} = 46.38$ | $V_{\Delta P} = 68\%$ |

Assume  $H_m$  is log normal distribution, we have

$$\overline{H_m} = \bar{C}(\bar{\Delta P})^{\frac{1}{2}} \bar{\psi} \bar{\zeta} \sqrt{\frac{\ln N}{2}} \quad (3.26)$$

$$V_{H_m}^2 = V_C^2 + \left(\frac{1}{2} V_{\Delta P}\right)^2 + V_\psi^2 + V_\zeta^2 + \left(\frac{1}{2} V_{\ln N}\right)^2 \quad (3.27)$$

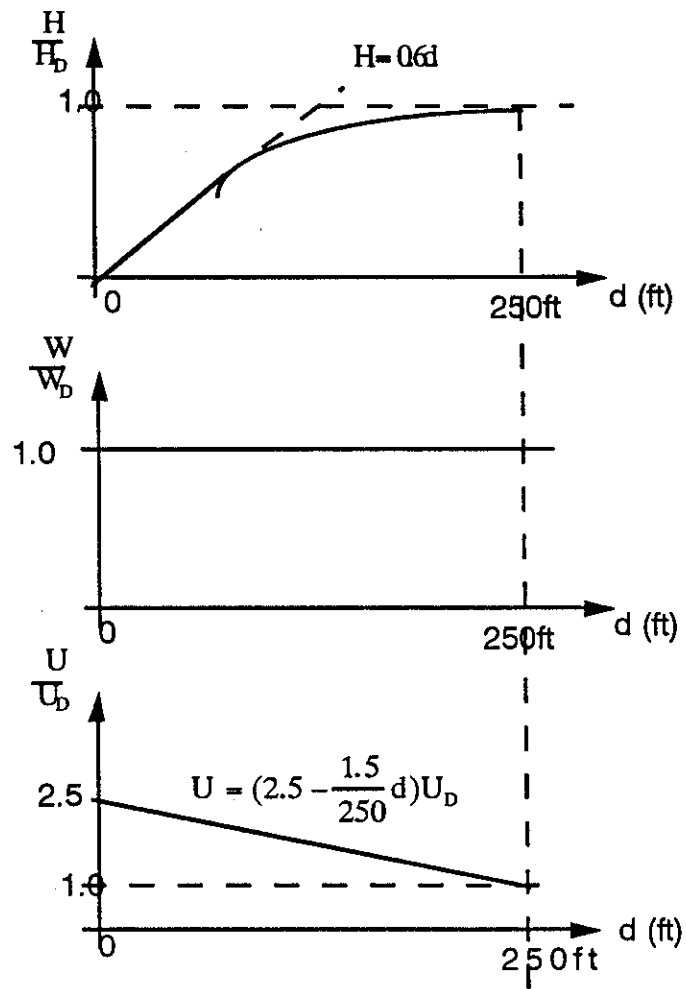
The average return period (ARP) was computed using Equation

$$ARP = \frac{1}{\lambda[1 - F(H_{e, \max})]} \quad (3.28)$$

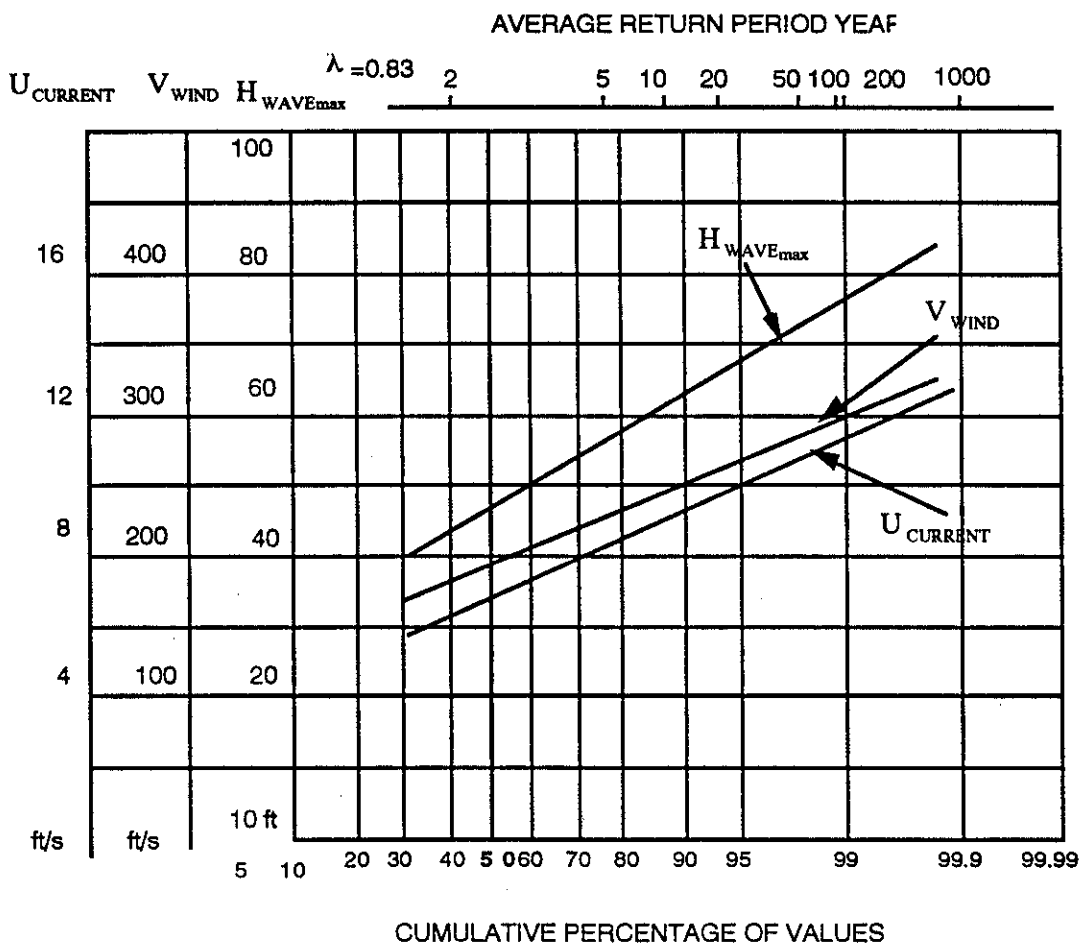
where  $F(H_{e, \max})$  is the cumulative percentage of  $H_{e, \max}$  values equal to or less than a given value, and  $\lambda$  is the average number of important wave-generating hurricanes affecting this area each year. A value of  $\lambda = \frac{76}{93} = 0.817$  was used.

With the same procedure, we can get the ARP of Maximum wind velocity and current velocity. See Fig.3.2.





**Fig. 3.1 Shoaling Effect**



**Fig. 3.2 Environmental Loading Return Period**

## Chapter 4. Environmental Force on the MODU

### 4.1. Hurricane Loading

There are three major hurricane loads on an MODU: wind load, and hydrodynamic wave and current load (Figure 4.1).

#### 4.1.1 Characterization of Wind Load

The wind force acting on a moored floating MODU can be determined using Equation (4.1):

$$F_w = C_w \sum (C_s C_h A) V_w^2 \quad (4.1)$$

where:

$$F_w = \text{wind force, lb.(N)} \quad (4.2)$$

$$C_w = 0.0034 \text{ lb} / (\text{ft}^2 \cdot \text{kt}^2) (0.615 \text{ N sec}^2 / \text{m}^4)$$

$$C_s = \text{shape coefficient}$$

$$C_h = \text{height coefficient}$$

$$A = \text{vertical projected area of each surface exposed to the wind, ft}^2(\text{m}^2)$$

$$V_w = \text{local wind speed, knots(m/sec)}$$

The projected area exposed to the wind should include all columns, deck members, deck houses, trusses, crane booms, derrick substructure and drilling derrick as well as that portion of the hull above the water line. (Except as noted below, no shielding should be considered.)

In calculating wind areas, the following procedures are followed:

- The projected area of all columns are included
- The blocked-in projected area of several deck houses are used instead of calculating the area of each individual unit. However, when this is done, a shape factor,  $C_s$ , of 1.10 is used.
- Isolated structures such as derricks and cranes are calculated individually.
- Open truss work commonly used for derrick mast and booms are approximated by taking 60 percent of the projected block area of one face.
- Areas are calculated for the appropriate hull draft for the given operating condition.
- Wind velocity increases with height above the water. In order to account for this change, a height coefficient,  $C_h$ , is included. The height coefficient,  $C_h$ , can be found in Table.

#### 4.1.2 Characterization of Current Forces

Current forces are normally treated as steady state forces in a mooring analysis. Current force acting on semisubmersible hulls can be calculated as:

$$F_{cs} = C_{ss} (C_d A_c + C_d A_f) U_c^2 \quad (4.3)$$

where:

$F_{cs}$  = current force, lb(N)

$C_{ss}$  = current force coefficient for semisubmersible hulls

$$= 2.85 \text{ lb} / (\text{ft}^2 \cdot \text{kt}^2) (515.62 \text{ N sec}^2 / \text{m}^4)$$

$C_d$  = drag coefficient (dimensionless)

= 0.6 for circular members; 1.0 for members having flat surfaces.

$A_c$  = summation of total projected areas of all cylindrical members below the waterline.

$$\text{ft}^2 (\text{m}^2)$$

$A_f$  = summation of projected areas of all members having flat surfaces below the waterline.  $\text{ft}^2 (\text{m}^2)$

### **4.1.3 Characterization of Wave Forces**

Interactions between ocean waves and a floating vessel results in forces acting on the vessel which can be conveniently split into three categories(Fig.4.2):

- (1) First order forces which oscillate at the wave frequencies. They induce first order motions which are also known as high frequency or wave frequency motions.
- (2) Second order forces with frequencies below wave frequencies. They induce second order motions which are also known as low frequency motions.
- (3) Steady component of the second order forces which is known as mean wave drift force.

#### **4.1.3.1 Wave Frequency MODU Motions**

The motions of the MODU at the frequency of the waves is an important contribution to the total mooring system loads, particularly in shallow water. These wave frequency motions can be obtained from regular or random wave model test data, or computer analysis using either time or frequency domain techniques. The method used in the paper is based on the widely used Morison Equation.

**Wave Kinematics:** Storm seas are generally directional seas. Directional seas can be considered as comprising of numerous unidirectional seas. The forces calculated in the directional seas are the product of a directional spreading factor and the forces calculated by the uni-directional wave theory. The wave data used here is all directional wave height. The directional spreading factor is assumed to be one.

The Linear or Airy wave theory is used here to characterize the wave kinematics. For uni-directional (long-crested) waves, water particle horizontal velocities,  $u_w$  and accelerations,  $a_w$  are

$$u_w = (\pi H / T) e^{kz} \cos(\theta) \quad (4.4)$$

and,

$$a_w = (2\pi^2 H / T^2) e^{kz} \sin(\theta) \quad (4.5)$$

where  $k$  is the wave number ( $k = 2\pi / L$ ),  $z$  is the vertical coordinate which is zero at the still water level and positive upward, and  $\theta$  is the wave phase angle ( $\theta = kx - \omega t$ ,  $\omega$  is the wave circular frequency,  $\omega = 2\pi / T$ ,  $x$  is the horizontal coordinate measured from the wave crest, and  $t$  is the time coordinate).

Local Forces: The total hydrodynamic force per unit length,  $F$ , is comprised of a drag force,  $F_d$ , and an inertia force,  $F_i$ :

$$F = F_d + F_i \quad (4.6)$$

where,

$$F_d = C_d (\rho / 2) (D) u |u| \quad (4.7)$$

$$F_d = K_d u |u|$$

and,

$$F_i = C_m (\rho \pi D^2 / 4) a \quad (4.8)$$

$$F_i = K_m (a)$$

The total lateral force can be calculated by integrating the local forces over the entire structure.

#### 4.1.3.2 Mean Wave Drift Force

The mean wave drift force is induced by the steady component of the second order wave forces. The determination of mean drift force requires motions analysis computer programs or model tests. Design curves for estimating mean wave drift forces for semisubmersibles are provided in Reference[12] (Fig.4.3). The curves are applicable to typical MODU type vessels.

#### 4.1.3.3 Low Frequency Vessel Motions

Low frequency motions are induced by the low frequency component of the second order wave forces which in general are quite small compared to the first order forces. Sometimes the second order forces are amplified through resonance into motions which can become very large and neglecting low frequency motions can provide non-conservative answers. But due to the difficulty in predicting the magnitude of resulting low frequency tensions, their effect is neglected.

### 4.2. Mooring System Capacity

Generally, the mooring system of a semi-submersible is as show in Figure 4.4. The problem of the mooring system failure probability is a kind of system probability. Detailed analysis will be done in later research. Here, as preliminary study, we assume the total expected lateral capacity of the mooring system is  $\overline{R_u}$ .

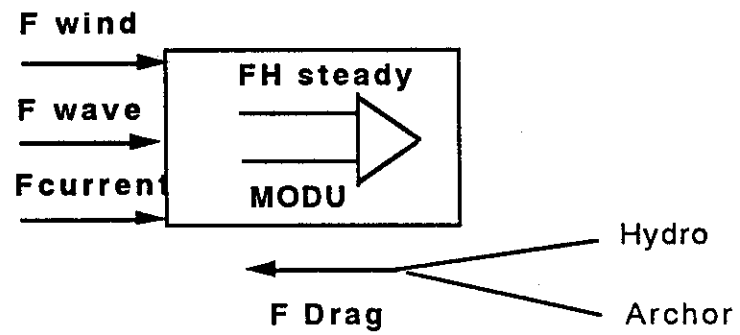
There are two modes of mooring system failure. One is that the horizontal hurricane loads is larger than the total anchor holding force, so the anchors will drag. The other is that the mooring system is broken, so the MODU will be floating. We let,

$\overline{R_{u1}}$ , denotes failure mode one (anchors dragging)

$\overline{R_{u2}}$ , denotes failure mode two (no anchors dragging)



Here, we just assume that if one anchor in the mooring system is dragging, then the others will all be in dragging condition. Or if one mooring chain is broken, then the others will all break.



**Fig. 4.1 Loading on MODU**

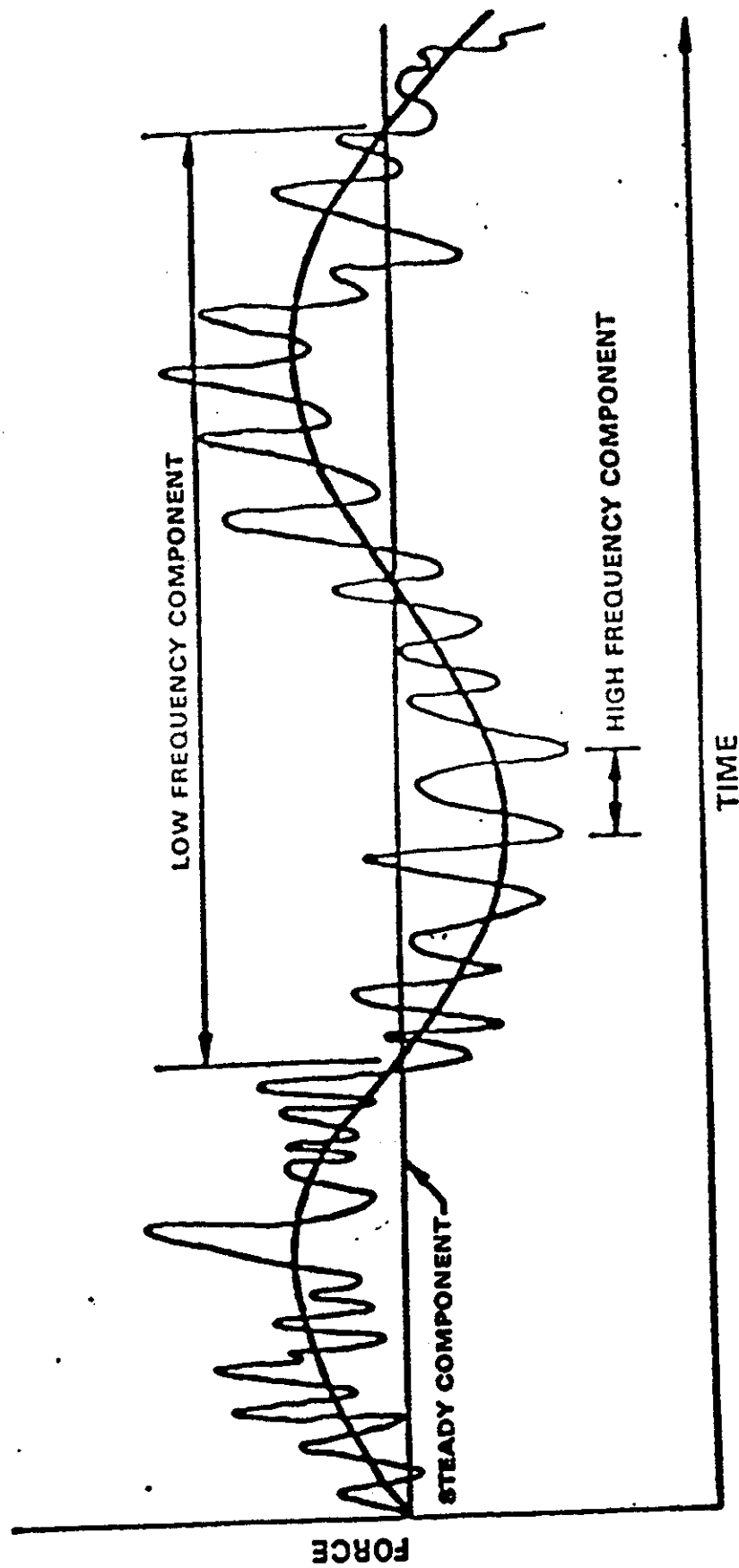


Figure 4.2 Wave Force Components

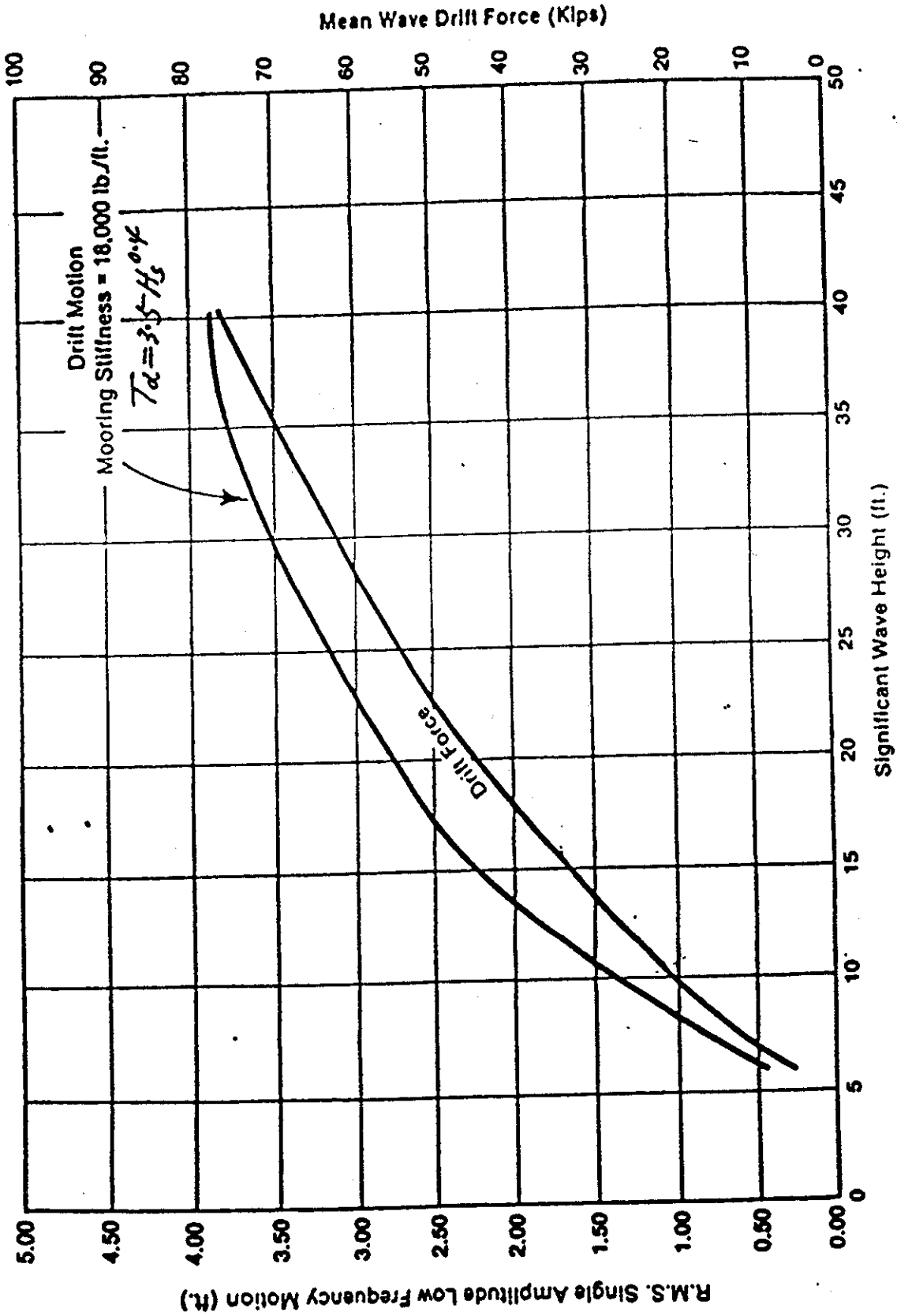


Figure 4.3a Wave Drift Force and Motion for Semisubmersibles  
Beam Seas

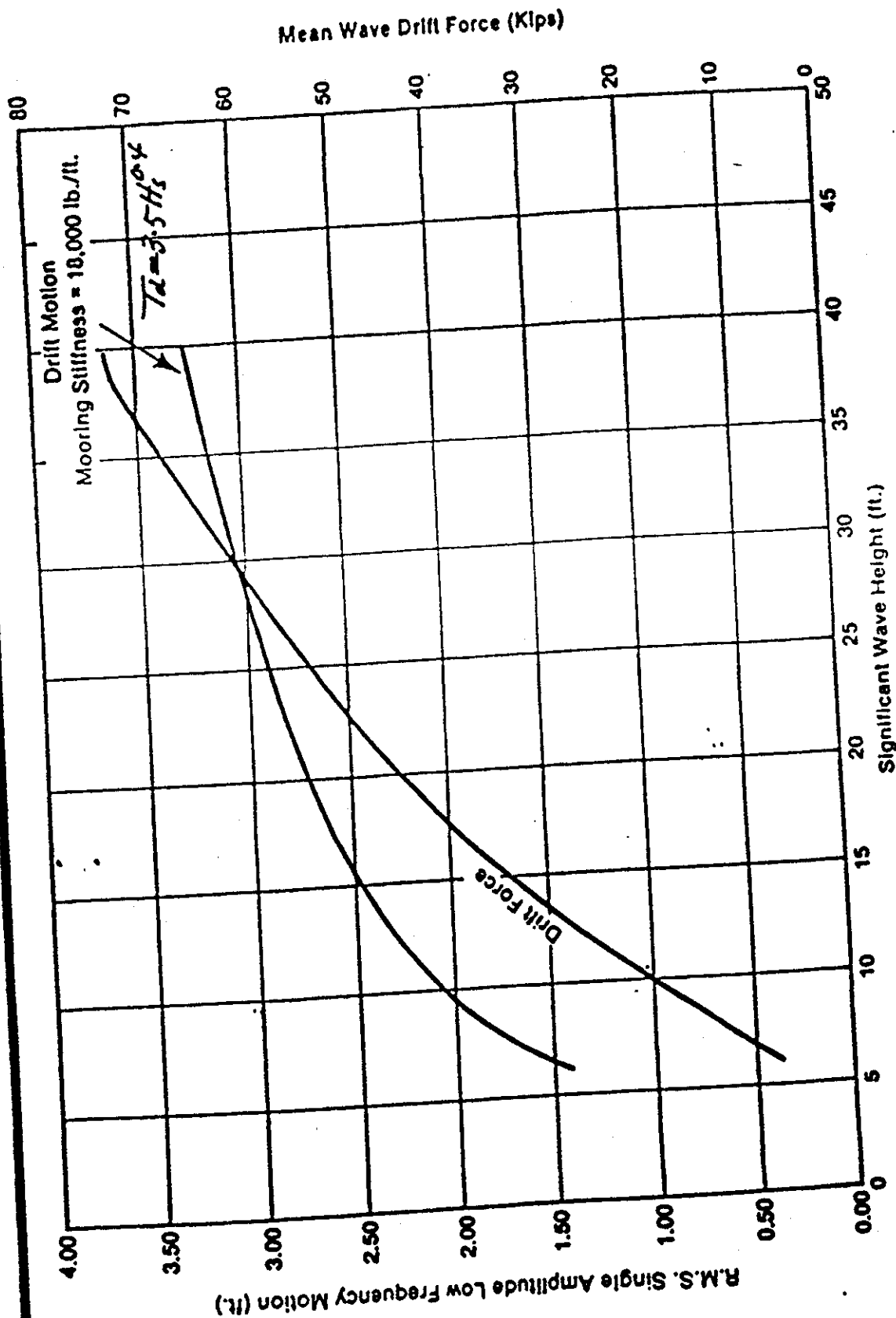
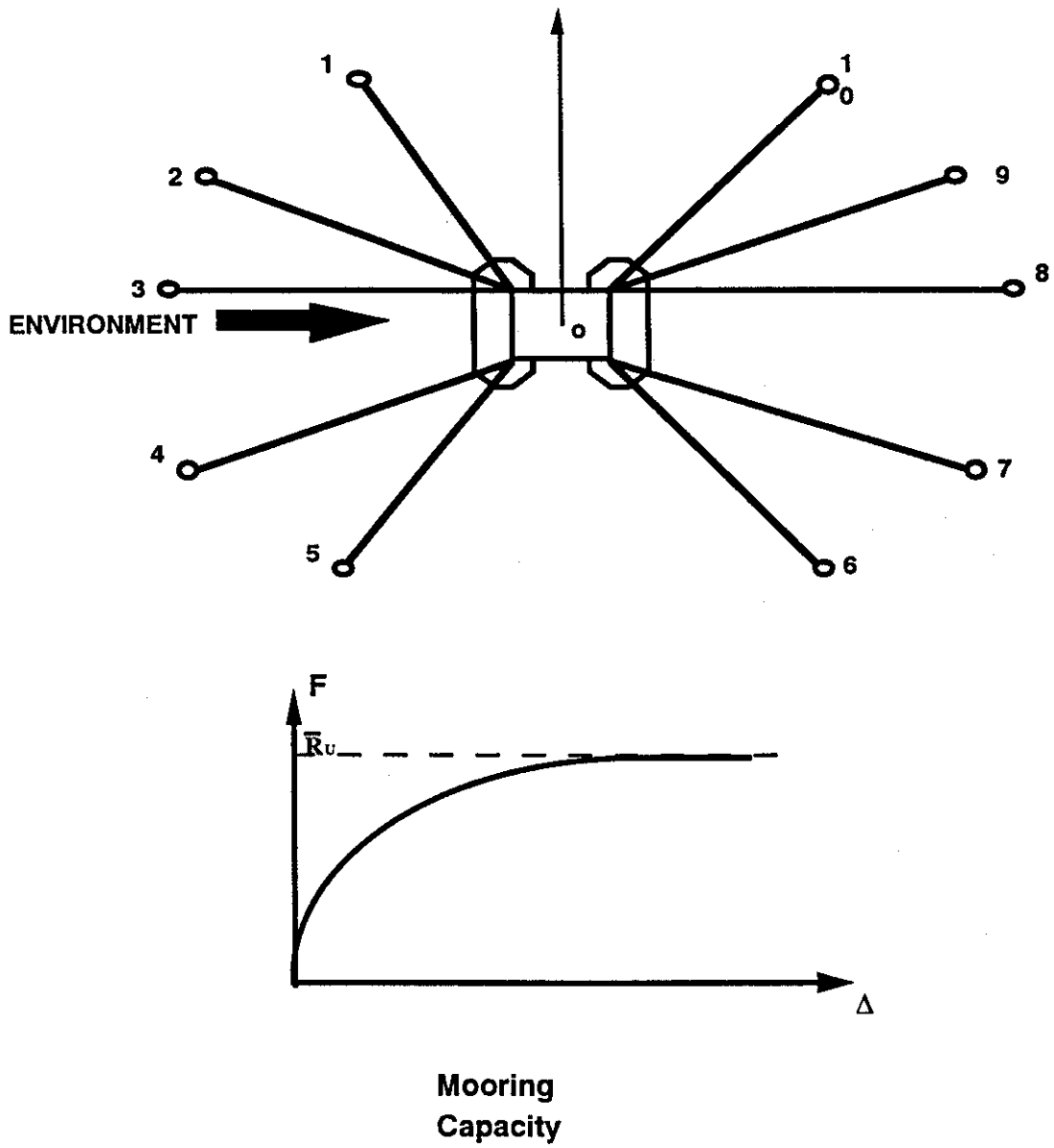


Figure 4.3b Wave Drift Force and Motion for Semisubmersibles  
Bow Seas



**Fig. 4.4 Mooring System Configuration**

## Chapter 5. MODU Moving Modeling

### 5.1 MODU Moving Modes

There are two moving modes associated with the depth of the water and the draft of the MODU. They are defined as:

$$T < d + \Delta d$$

case A: MODU Floating

$$\Delta d + d < T < \Delta d + d + \eta_{\max}$$

case B: MODU Skipping

$$T > \Delta d + d + \eta_{\max}$$

case C: MODU STOP

where,

$$T = \text{draft of the MODU}$$

$$d = \text{depth of the water}$$

$$\eta_{\max} = \text{maximum wave height}$$

$$\Delta d = \text{surge of sea surface}$$

## 5.2. MODU Moving Distance Modeling

### 5.2.1. Case A: MODU Floating

#### 5.2.1.1 Free Floating Condition

During a short period of time ( $\Delta t$ ), the MODU is assumed to move with a steady velocity. We assume that the total hurricane horizontal steady force is equal to the hydrodynamic force. (See Fig. 4.1)

$$\begin{aligned} F_{Hsteady} &= F_{wave} + F_{wind} \\ &= F_{Hydro} = [C_D A_p \rho / 2] [V_{MODU} - V_{Current}]^2 \end{aligned} \quad (5.1)$$

where

$$C_D = 0.7$$

$A_p$  = Projected Area

$$\rho = 64 \text{ lb/ft}^3$$

$F_{Wind}$  = Steady wind force

$F_{Wave}$  = Mean wave drift force

So:

$$V_{MODU} = \sqrt{\frac{F_{Wind} + F_{Wave}}{C_D A_p \rho / 2}} + V_{Current} \quad (5.2)$$

and,

$$\Delta_{move} = V_{MODU} \Delta t \quad (5.3)$$



where,

$\Delta t$  = hurricane simulation time period

case A-- MODU Floating

### 5.2.1.2 Dragging Condition

Here, we also assume the MODU moves with a steady velocity, so the total hurricane horizontal steady force minus anchor dragging force is equal to the hydrodynamic force.

$$\begin{aligned} F_{Hsteady} &= F_{wave} + F_{wind} - F_{Anchor} \\ &= F_{Hydro} = [C_D A_p \rho / 2] [V_{MODU} - V_{Current}]^2 \end{aligned} \quad (5.4)$$

where,

$$C_D = 0.7$$

$A_p$  = Projected Area

$$\rho = 64 \text{ lb/ft}^3$$

$F_{Wind}$  = Steady wind force

$F_{Wave}$  = Mean wave drift force

So

$$V'_{MODU} = \sqrt{\frac{F_{Wind} + F_{Wave} - F_{Drag}}{C_D A_p \rho / 2}} + V_{Current} \quad (5.5)$$

and,

$$\Delta_{move} = V'_{MODU} \Delta t \quad (5.6)$$

Here, the dynamic anchor drag force is assumed as,

$$F_{dynamic} = \epsilon F_{static} \quad (5.7)$$

where,

$$\bar{\epsilon} = 0.5, \quad V_e = 30\%.$$

t = hurricane time period

case A--MODU Floating

### 5.2.2 Case B: MODU Skipping

When the MODU moves in skipping mode, during a wave period, the MODU will move when  $T < \Delta d + d + \eta_{max}$ , and it will stop when  $T > \Delta d + d + \eta$ . Since wave period is usually short, we can not assume the MODU moves with a steady velocity now. A moving differential equation needs to be solved:

$$F_{Wave} + F_{Wind} + [C_D A_p \rho / 2](V_{Current} - V_{MODU})^2 = M \dot{V}_{MODU} \quad (5.8)$$

### 5.3. MODU Collision Modeling

The surrounding structures are assumed that they are located within several large target circles with radius  $R_i$  from 0.5 to 5 nm. Collision happens when the MODU runs into one of these circles and collides with structures within the circle. From the simulation, the MODU's moving route is determined. If the distance between the moving route and the center of the circle is less than  $R_i$ , we say, the MODU is running into the circle. To determine whether the MODU collides with structures or not within the circle, a pre-prepared simulation was performed.

During the simulation, the MODU is assumed to moving at a straight line within the circle before collision happens. The direction in which the MODU runs into is assumed uniformly distributed from  $0^\circ - 180^\circ$ . Target structures are also assumed uniformly distributed within the circle. With a given circle radius and the number of structures within the circle, the distance between these structures and the MODU route is determined. The collision happens if one of these distance is less than safety distance, say 100m. With a given  $R_i$  and  $N$ , the process is repeated many times to get the probability of collision on the condition of MODU runs into the circle. For different  $R_i$  and  $N$ , the simulation results are presented in Figure. 5.1.

Several conclusion can be drawn from the simulation result:

1.  $R \leq 2$  nm, the collision probability increases rapidly from 30% to 80% when  $N$  increases from 10 to 30. When  $N$  is larger than 40, the collision probability is very high and does not change much when  $N$  increases.
2.  $R \geq 3$  nm, the collision probability increases slowly with  $N$ .

3. In both cases, the collision probability increases rapidly at first, then slows down when  $N$  is large enough.

4. From the Fig.5.1, we found, for most general circle (radius  $R=2.4\text{nm}$  and number of structures within the circle  $N=40$ ), the collision probability within the circle is approximately 60%.

Probability of Collision vs. Structure numbers

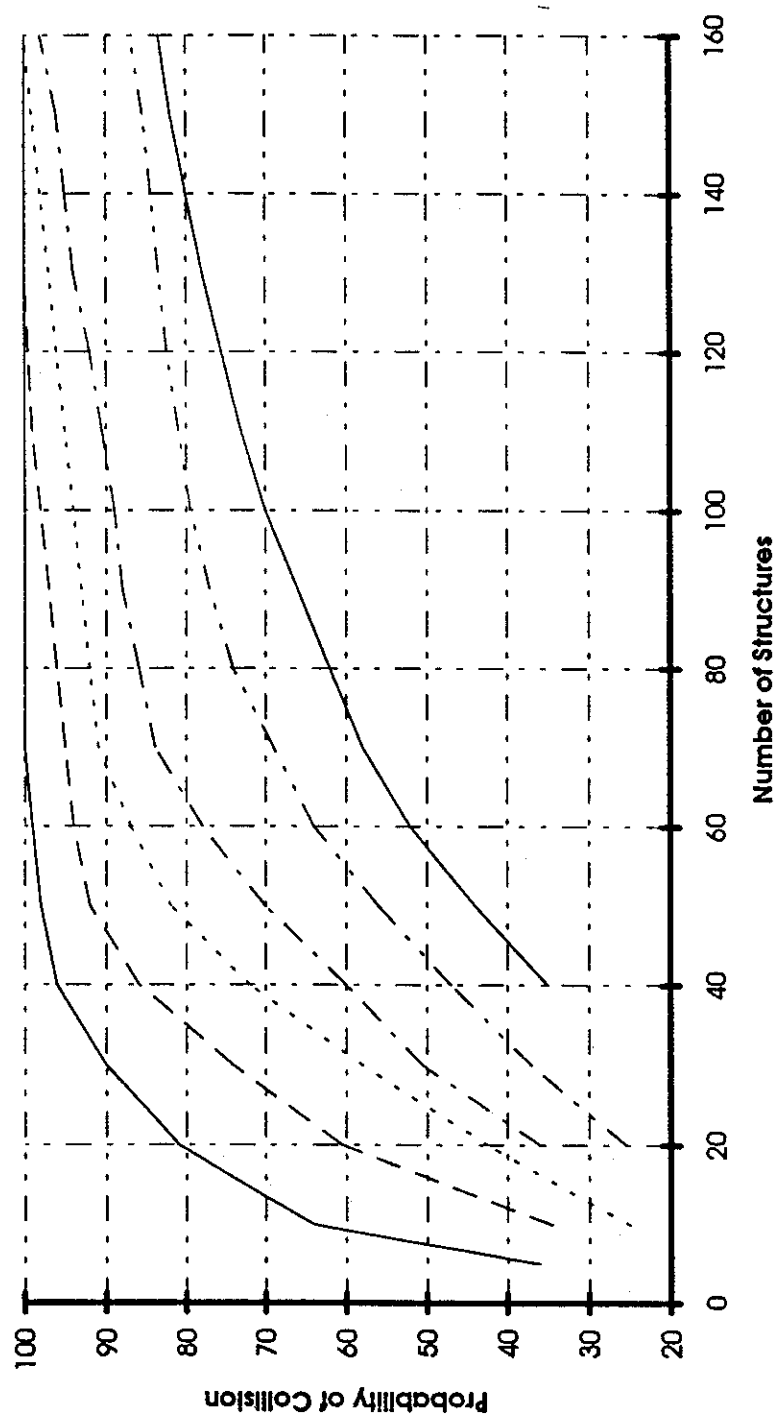


Figure 5.1 Collision Probability vs. Structure Density within Given Target Circles

## **Chapter 6. Monte-Carlo Simulation**

Simulation is a technique for conducting experiments in a laboratory or on a digital computer in order to model the behavior of a system. Monte-Carlo simulation is usually used for problems involving random variables of known or assumed probability distributions. Using statistical sampling techniques, a set of values of the random variables are generated in accordance with the corresponding probability distributions. These values are used to obtain a "sample" solution. By repeating the process and generating several sets of sample data, many sample solutions can be determined. Statistical analysis of the sample solutions is then performed.

The MODU's moving in a hurricane is a very complicated process. The environmental force and the MODU moving direction are time-dependent variables. The process can be modeled by direct computer simulations using the probability models for the hurricane parameters, the MODU's approximate to the site, and the number of hurricanes.

**The simulation procedure can be summarized as follows:**

- 1) Select a reference frame in which the site is located.(See Fig.6.1)
- 2) Generate the number,  $n$ , of hurricanes which occur during the period of consideration, i.e., 1 years, within the reference frame using a Poisson distribution with an occurrence statistics at the location, i.e.,  $\gamma_h$ .
- 3) Generate a sets of random variables  $X, \Delta P, R, \varphi, V_H$  according to the distribution and joint distribution functions given in Section 2.3.
- 4) For each set of the parameters generated in 3), calculated the wind, wave and current force time histories at the site according to the parameter models. If the MODU mooring system is failure, then determine the MODU moving route time history during the hurricane.
- 5) Check if the distance between large facilities and the MODU moving route is smaller than the safety distance.
- 6) Repeat steps 2-5  $N$  times(trials) and record the number of trials in which the collision happens, say  $c$ , the relative frequency  $c/N$  for large  $N$  is the estimate of the probability that the MODU will collide with large facilities in 1 years.

The detailed procedure is illustrated in Fig.6.2 , Fig.6.3 and later Sections.

## 6.1. Detailed Computer Simulation Approach

### 1) Select a reference frame in which the site is located.(See Fig.6.1)

A reference is selected in which the MODU is located. The X-axis is chosen as parallel to the coastal line, and Y-axis is chosen as perpendicular to the coastal line. The user determined information includes:

- a) Original point of the reference (longitude and latitude);
- b) The width of the reference frame ( $X_{\max}-X_{\min}$ );
- c) The distance from X-axis to coastal line;
- d) The water depth at the site of MODU's location.

Based on such information, x and y coordinates of the MODU in the reference frame are determined.

X and Y coordinates and radius of large facility circles are determined by users either, and the corresponding collision probabilities can be found out from Figure 5.1.

### 2) Generate the number, n, of hurricanes which occur during the period of consideration, i.e., 1 years, within the reference frame using a Poisson distribution with an occurrence statistics at the location, i.e., $\gamma_h$ .

For example, if the reference frame is chosen at area C, with width 100 nm, we know the occurrence rates at a point in region C is 0.00163/year-nm, so the occurrence rate within the reference frame is 0.163/year.

### 3) Generate a sets of random variables $X, \Delta P, R, \phi, V_h$ according to the distribution and joint distribution functions given in Section 2.3.



4) For each set of the parameters generated in 3), calculated the wind, wave and current force time histories at the site according to the parameter models. If the MODU mooring system is failure, then determine the MODU moving route time history during the hurricane.

As in Fig.6.1, the hurricane is assumed to be a storm traveling along a straight line with a given translation speed and direction. And the changes in the storm parameters over the life of the storm are not considered.

The coordinate of the hurricane center is:

$$X_H = X_0 + V_H t \cos \varphi \quad (6.1)$$

$$Y_H = V_H t \sin \varphi \quad (6.2)$$

The coordinate of the mooring MODU and large facilities are  $(X_M, Y_M)$  and  $(X_{F_i}, Y_{F_i})$ ,  $(i=1, \text{ to } n, \text{ where } n \text{ is the number of large facilities around the MODU})$ .

|        |                    |   |                                 |
|--------|--------------------|---|---------------------------------|
| where, | $X_0$              | : | Uniform distribution            |
|        | $\varphi$          | : | Triangular distribution         |
|        | $V_H, R, \Delta P$ | : | Jointly log normal distribution |

The distance between MODU and hurricane center is :

$$r = \sqrt{(X_H - X_M)^2 + (Y_H - Y_M)^2} \quad (6.3)$$

The environmental force acting on the MODU:

a) Wind force: The wind force acting on the MODU is calculated using the procedure given in section 4.1.1. The direction of the wind force  $\gamma_{Wind}$ , (polar angle in degree) is given by (refer to Fig. 6.1 for definition of  $\gamma$ ,  $\beta$ ,  $\alpha$ , and  $\theta$ ):

$$\gamma_{Wind} = \beta_{Wind} + \varphi + 90^0 \quad (6.4)$$

where:

$$\beta_{Wind} = \theta + \alpha + 90^0 \quad (6.5)$$

$$\theta = 90^0 - \varphi + \arctg \frac{Y_H - Y_M}{X_H - X_M} \quad X_H < X_M \quad (6.6)$$

$$\theta = 270^0 - \varphi + \arctg \frac{Y_H - Y_M}{X_H - X_M} \quad X_H > X_M \quad (6.7)$$

$$\alpha = 22 + 10 \cos \theta \quad (6.8)$$

b) Wave force: The wave force is calculated using the procedure given in section 4.1.2. The direction of the wave force  $\gamma_{Wave}$ , (polar angle in degree), is given by:

$$\gamma_{Wave} = \beta_{Waves} + \varphi - 90^0 \quad (6.9)$$

where:

$$\beta_{Wave} = \theta + \alpha + a \left( \frac{r}{R} \right)^b - 90^0 \quad (6.10)$$

$$a = 144 + 39 \cos \theta - 25 \sin \theta - 15 \cos 2\theta \quad (6.11)$$

$$b = -0.08 \quad (6.12)$$

Here  $\alpha, \theta$  are the same as in wind force.

c) Current Force: The current force is calculated using the procedure given in section 4.1.3. Here we assume the direction of the current force is the same as that of the wave force.

Then, as shown in Fig.6.4, the total environmental forces acting on the MODU is:

$$\vec{F}_{Total} = \vec{F}_{Wave} + \vec{F}_{Wind} + \vec{F}_{Current} = \vec{F}_1 + \vec{F}_2 \quad (6.13)$$

$$|F_{Total}| = F_1^2 + F_2^2 + 2F_1F_2 \cos(\gamma_1 - \gamma_2) \quad (6.14)$$

where  $F_1, F_2$  denotes wind and wave forces. The direction,  $\gamma_{Total}$  (polar angle in degree) is:

$$\gamma_{Total} = \gamma_1 + \arccos\left(\frac{F_{Total}^2 + F_1^2 - F_2^2}{2F_{Total}F_1}\right) \quad (6.15)$$

During the hurricane time history, in each short time period, i.e., 1 hour, we check whether the environmental force exceeds the MODU mooring capacity. If the mooring system is failure, then the MODU will move in the direction the same as the direction of the total environmental force, with velocity  $V_M$ , where  $V_M$  is calculated using the procedure given in section 5.2.

After  $\Delta t$ , i.e., 1 hour, the hurricane center and the MODU will move to a new place. The new position of hurricane center and the MODU are:

$$X_H' = X_H + V_H \Delta t \cos \varphi \quad (6.16)$$

$$Y_H' = Y_H + V_H \Delta t \sin \varphi \quad (6.17)$$

and,

$$X_M' = X_M + V_M \Delta t \cos \gamma_{Total} \quad (6.18)$$

$$Y_M' = Y_M + V_M \Delta t \sin \gamma_{Total} \quad (6.19)$$

The above procedure is repeated until the MODU collides with large facilities or the MODU stops.

5) Check if the distance between large facilities and the MODU moving route is smaller than the safety distance.

The MODU runs into the circle when the distance between the center of the circle and the MODU moving route, say  $d$ , is less than  $R_{Safe}$ , where  $d$  is given by the following procedure:

The linear equation of the MODU moving route during one short time period  $\Delta t$  is:

$$Y - Y_M = \operatorname{tg}(\gamma_{Total})(X - X_M) \quad (6.20)$$

So,

$$\operatorname{tg}(\gamma_{Total})X - Y + Y_M - X_M \operatorname{tg}(\gamma_{Total}) = 0 \quad (6.21)$$

We let,

$$A = \operatorname{tg}(\gamma_{Total})$$

$$B = -1$$

$$C = Y_M - X_M \operatorname{tg}(\gamma_{Total})$$

Then, we have,

$$d = \frac{|AX_{F_i} + BY_{F_i} + C|}{\sqrt{A^2 + B^2}} \quad (6.22)$$

where,  $X_M \leq X_{Fi} \leq X'_M$  and  $Y_M \leq Y_{Fi} \leq Y'_M$  are the coordinates of large facilities.

6) Repeat steps 2-5  $N$  times(trials) and record the number of trials in which the collision happens, say  $c$ , the relative frequency  $\frac{\sum C_i P_i}{N}$  for large  $N$  is the estimate of the probability that the MODU will collide with large facilities in 1 years.

During the simulation, record the number of trials in which the MODU runs into each circle,  $C_i$ , thus for large  $N$ , the estimate of the probability of collision is:

$$P(\text{runs into circle}) = \frac{\sum C_i}{N} \quad (6.23)$$

$$P(\text{collides with structure}) = \frac{\sum C_i P_i}{N} \quad (6.24)$$

$$P(\text{collides with given target circle } i) = \frac{C_i}{N} \quad (6.25)$$

$$P(\text{collides with structure within certain circle } i) = \frac{C_i P_i}{N} \quad (6.26)$$

where,

$N$  = number of trials;

$C_i$  = number of trials in which the MODU runs into the given target area;

$P_i$  = probability of collision with structures within the given target circle  $i$ , with given radius of circle( $R_i$ ) and number of structures within the circle( $N_i$ ),  $P_i$  can be found out from Fig.5.1.

## 6.2. Sample Size and Variance Reduction Techniques

### 6.2.1 Sample size

The simulated data according to Monto-Carlo method should be treated as a sample of experimental observation, and therefore, is subjected to sampling error. The coefficient of variation of the probability based on simulation is (Reference[8]):

$$\text{COV} = \frac{1 - P_c}{\sqrt{NP_c}} \quad (6.27)$$

in which  $P_c$  is the probability of collision, and  $N$  is the sample size. It is seen that the C.O.V. is dependent on the number of simulations  $N$  and the probability of collision,  $P_c$ . Therefore, since the estimated probability  $P_c$  is small which is usually the case,  $N$  should be large enough to decrease the error. For example, for  $N=5000$ , the coefficient of variation is approximately 45% at  $P_c=0.001$ . The standard error of this estimate is given by:

$$\text{SE}(p) = \sqrt{\frac{P_c(1 - P_c)}{N}} \quad (6.28)$$

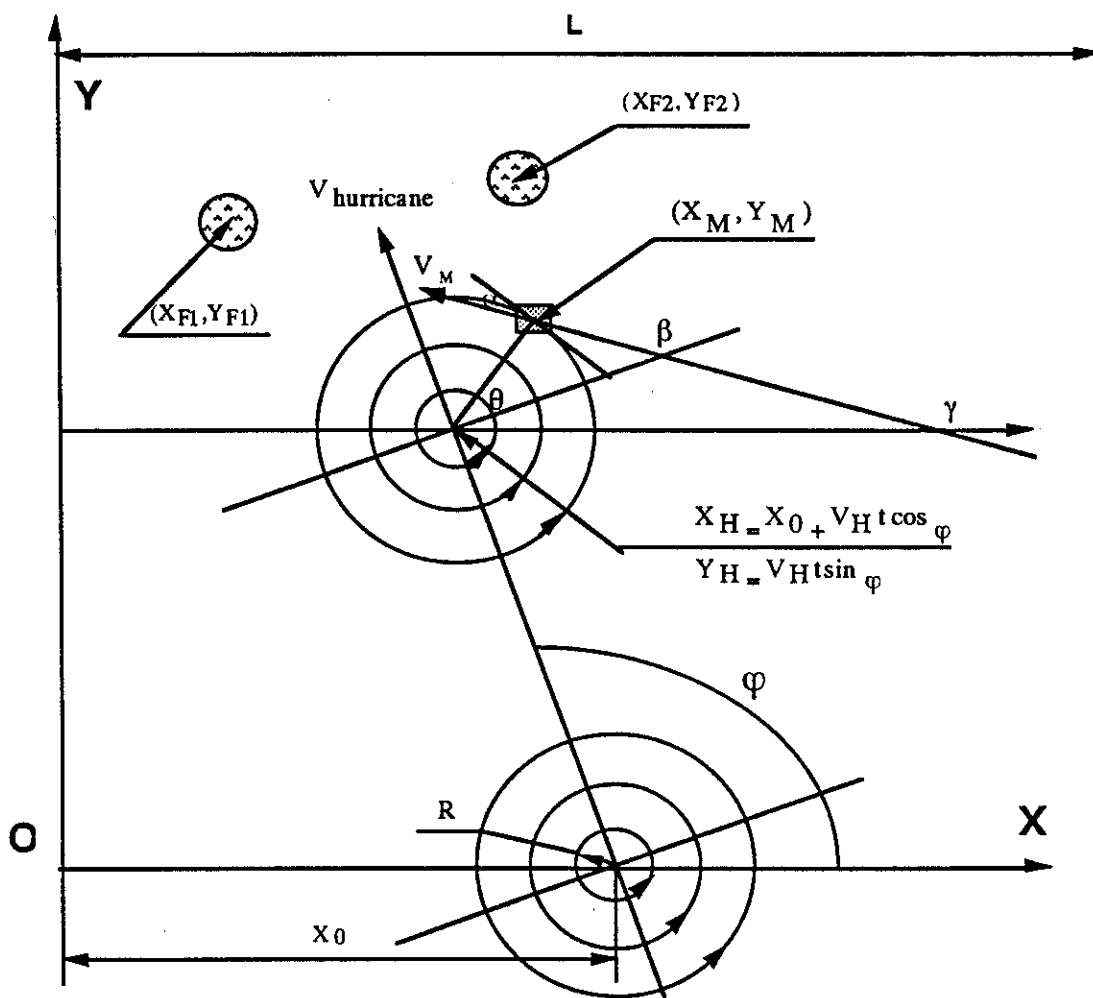
Usually, it should have  $\frac{100}{P_f}$  simulations to obtain reasonable accuracy. E.g., for  $P_f = 10^{-3}$ , need 100,000 simulations.

### 6.2.2 Variance Reduction Techniques

Statisticans and practitioners have developed several techniques for drawing random samples. The Latin Hypercube sampling is used in the program. It recreates the input distribution through sampling in fewer iterations when compared with the Monte Carlo method, especially if the input distribution is highly skewed or has some outcomes of low probability.

The key to Latin Hypercube sampling is stratification of the input probability distributions. Stratification divides the cumulative curve into equal intervals on the cumulative probability scale(0 to 1.0). A sample is then randomly taken from each interval or "stratification" of the input distribution. Sampling is forced to represent values in each interval, and thus, is forced to recreate the input probability distribution.

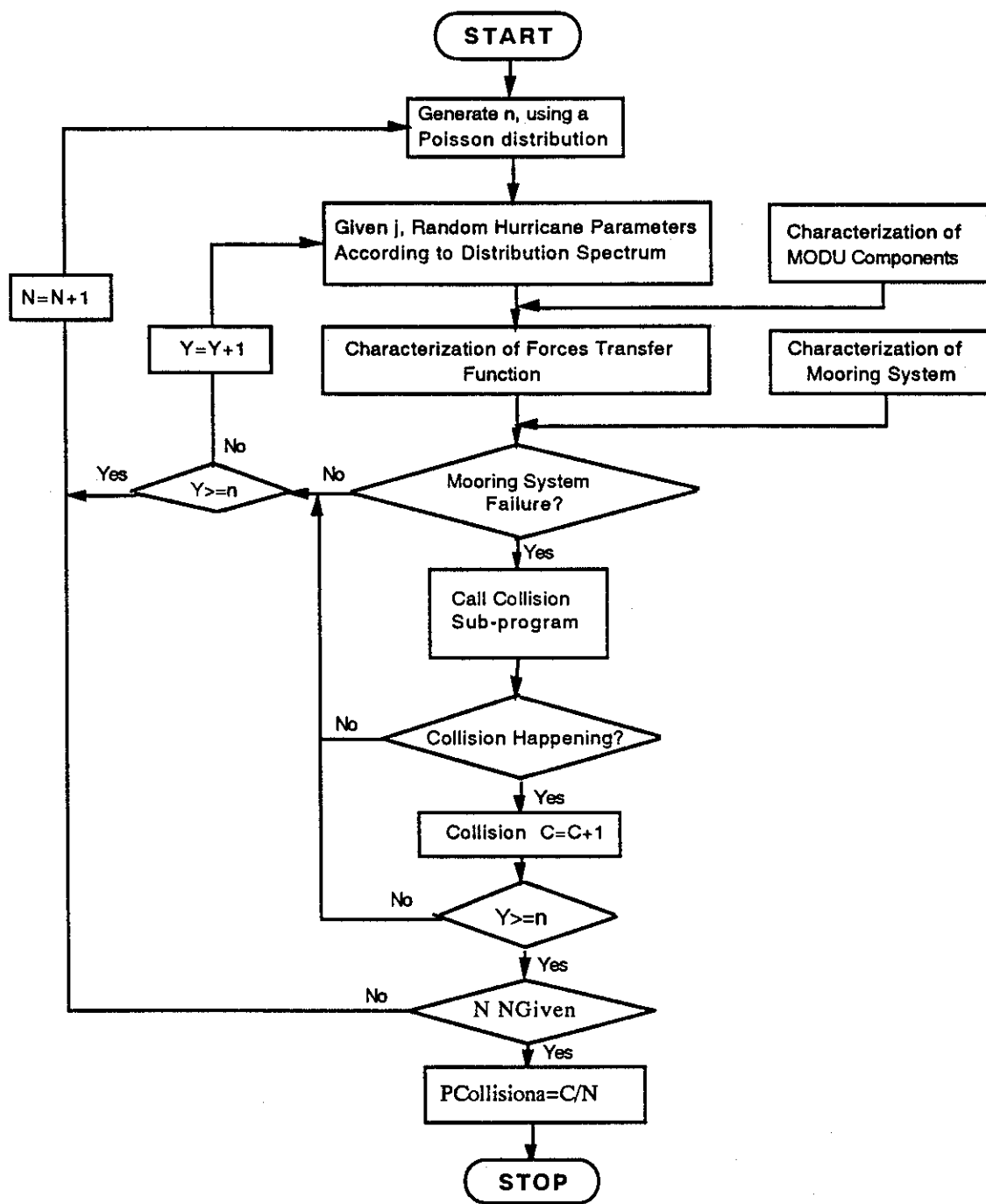
The technique being used during Latin Hypercube sampling is "sampling without replacement". The number of stratifications of the cumulative distribution is equal to the number of iterations performed. For example, for 100 iterations, 100 stratifications are made to the cumulative distribution. A sample is taken from each stratification. However, once a sample is taken from a stratification, this stratification is not sampled from again--its value is already represented in the sampled set. For sampling within a given stratification, the program chooses a stratification for sampling then randomly chooses value from within the selected stratification.



|                                  |                       |
|----------------------------------|-----------------------|
| $V_H, X_0, \varphi, R, \Delta P$ | Random variables      |
| $X_0$                            | Uniform distribution  |
| $\varphi$                        | Triangle distribution |
| $V_H, R, \Delta P$               | Jointly lognormal     |

**Fig. 6.1 Monte-Carlo Simulation Reference**





**Fig. 6.2 Monte-Carlo Simulation Procedure**

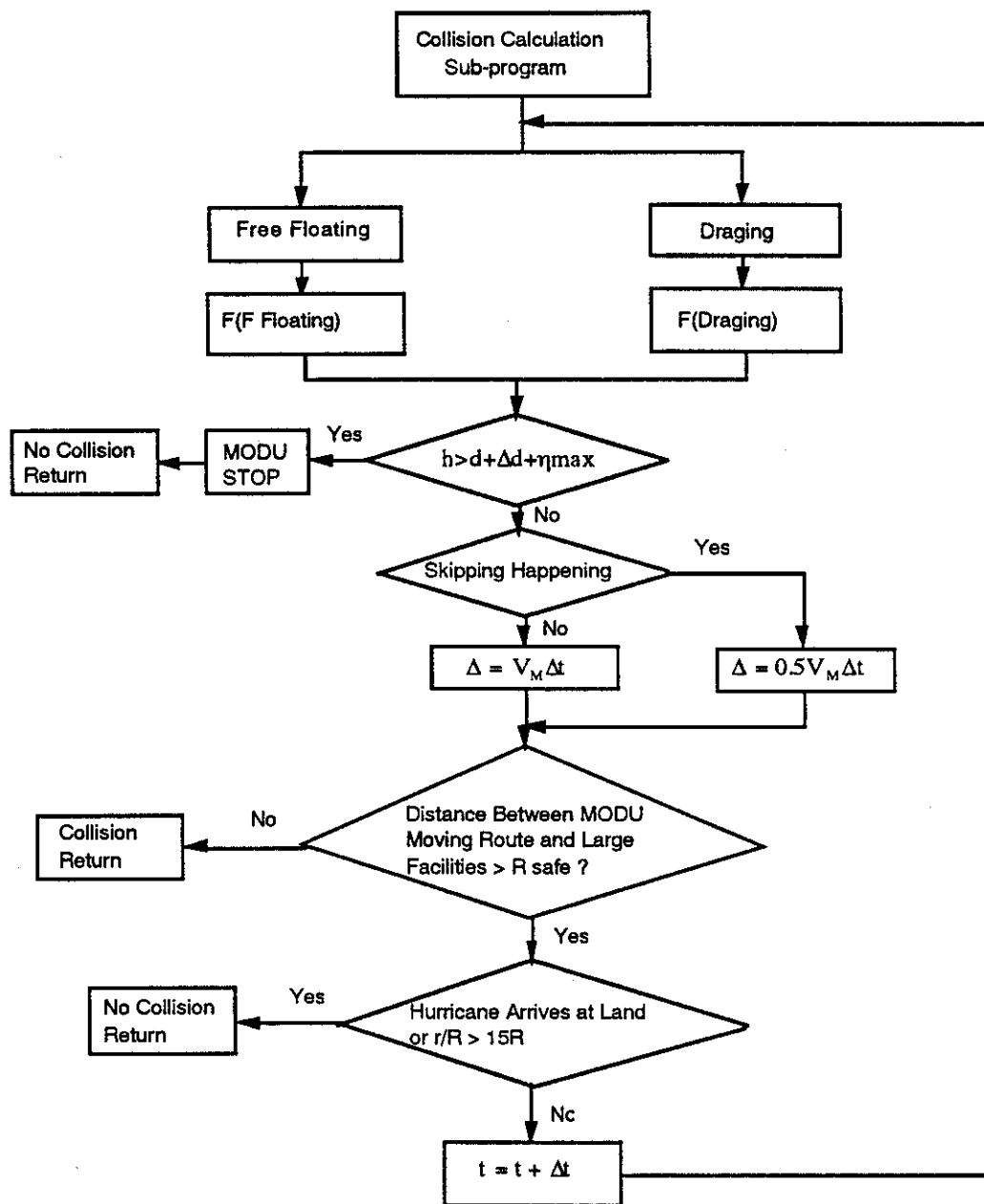
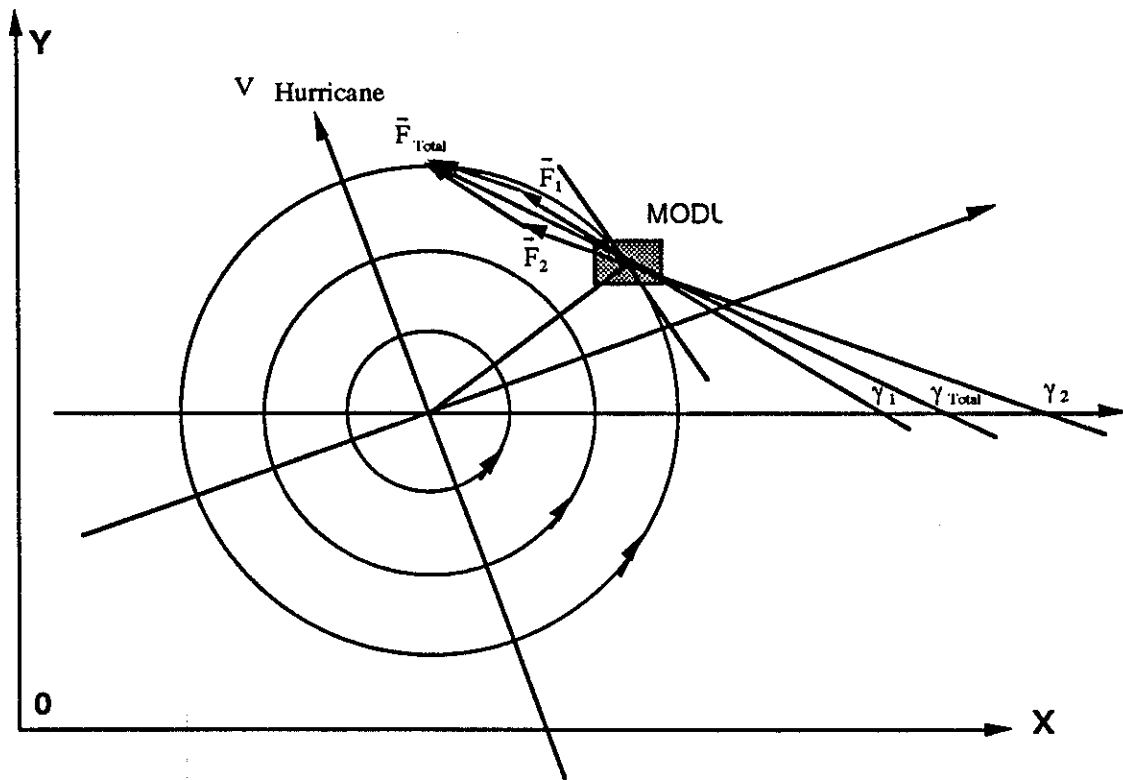


Fig. 6.3 Monte-Carlo Simulation Procedure



**Fig. 6.4 Environmental Force Configuration**

## Chapter 7. Model Application to "Zane Barnes"

In September 1992, hurricane Andrew swept through the eastern portion of the Gulf of Mexico (GOM). Five mobile offshore drilling units (MODUS) both experienced damage and inflicted significant damage on surrounding facilities. The Zane Barnes, Zapata Saratoga, and Treasure 75 all moved very significant distance during hurricane Andrew. The model discussed in this report was used to simulate the moving of "Zane Barnes" in the hurricane Andrew.

### 7.1 Simulation of MODU's Movement in the Hurricane

The principle dimensions of "Zane Barnes" is in Appendix 1. It was located at La-Grand Isle Block 87 with 200 ft depth of water in the Gulf of Mexico. (Longitude  $90^{\circ}5'$ , Latitude  $28^{\circ}40'$ ). The shoaling coefficient  $k$  is 0.97. The storm track of "Andrew" and storm parameters are presented in Fig. 7.1 and Fig. 7.2. (Refer to Reference [14]). As the hurricane loading on the MODU is large enough to break the mooring system only when  $r/R$  is less than 10, we chose the hurricane parameters during this period as the average of time step 5 and 6 (Fig. 7.2).  $\Delta P = 82 \text{ mb}$ ,  $V_F = 11 \text{ knots}$  and  $R = 15 \text{ nm}$ . The hurricane track direction is 140 degrees. The reference frame is selected as in Fig. 7.3. The original point is longitude  $90^{\circ}30'$  and latitude  $28^{\circ}25'$ . The simulation began when  $r/R$  was 10, ended when the hurricane center reached land or MODU stopped. We assumed that the mooring system was broken before it could drag in soil, so the MODU is free floating.

Since the mooring capacity has great influence on when the mooring system would be broken during hurricanes and the MODUs moving direction after broken, here we just assume there are three possible mooring capacities, 2300kips, 3000kips and 4000kips. That is, if the horizontal environmental force is greater than the mooring capacity, the mooring system will be broken.

From the result, it can be found that if the mooring capacity is low, the MODU moves to west, otherwise, the moving direction is northwest. Also from the report of Zane Barnes moving, we know that it was driven to northwest for about 30 nautical miles, stopped at South Timbalier(block 32) in a water depth of 45 feet. This may mean that its mooring capacity was about 4000kips. Under this assumption, the simulation results agree well with the report.

## **7.2 Study of the Probability of Collision**

Based on information from the MMS database, the major platform facilities were located within several target circles in the ST and GI area. The chosen representative semisubmersible, Zane Barnes, was sited in various locations and in various configurations (standard mooring, strengthened mooring). The probability of collision with major facilities was calculated and the result is presented in Figure 7.5. Several conclusions may be drawn from the result:

1. It is found that anything more than a one year hurricane storm will cause breakaways. The difference in mooring strength only results in different MODU moving route. In high structure density areas, it seems that mooring strength is not important to the collision probability. However, when the surrounding structures are far from the MODU, this difference may change the probability of collision much. In this case, it is still useful to test the various mooring systems for different mooring strength.
2. In large structure density area, the probability of collision may decrease greatly if anchors are designed to drag prior to any mooring line breaking since in this case the MODU will not move far. However, if the rig is to be located near subsea structures that could be damaged by a dragging anchor, the operator may use pile anchors or oversized drag anchors to preference the lines to break first.
3. The study shows that should a failure occur, collision with a platform was likely. This may due to the high density of platforms within the area. However, a series of simulations was

conducted varying the location of MODU, so the distance from the MODU to the closest target circles. The result of these simulations are shown in Figure 7.5. It can be seen that the most likely collision target circle around the MODU is the one located at north-west to the MODU. So a MODU should be moored as far as possible to the nearest north-west target circles. For example, if Zane Barnes were moored at (50,18) instead of (40,28) which is 15 nm to the south-east, the probability of collision will be half of before.

4. Parametric studies indicate very significant probabilities of collision in ST and GI area. This may due to the high density of structures in these area. The best ways to decrease the probability of collision in these areas are to design anchors to drag before any mooring line breaking or to site MODUs to deep water, if possible.

# HURRICANE ANDREW FINAL TRACK

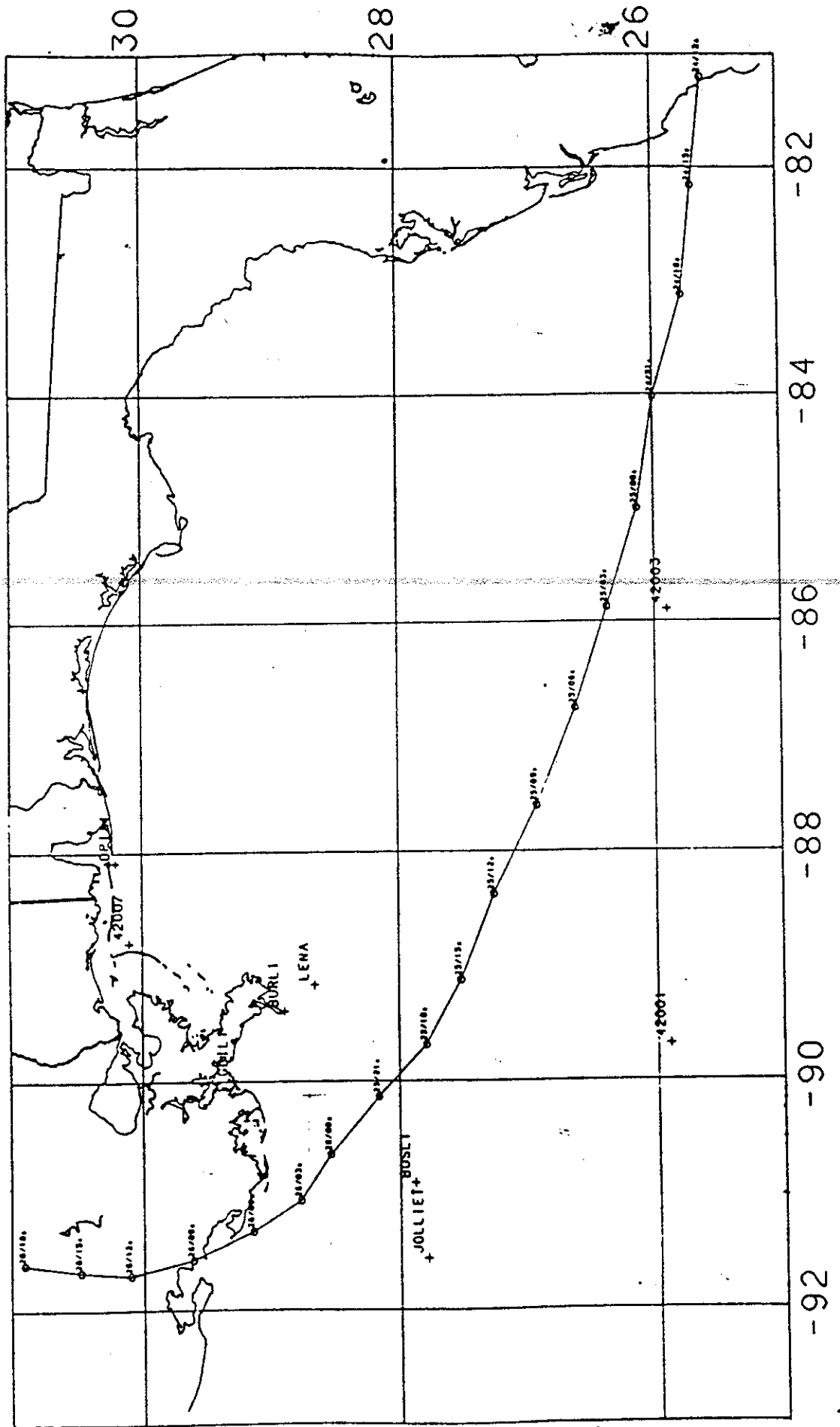


Figure 7.1 Storm Track for Hurricane Andrew

1. Storm parameters and track used for numerical model simulation of boundary layer wind field

Typical Cyclone Input Data

Project ANDREW JIP

Form # 9208 Name ANDREW

Duration of Hindcast 60 hours

STEP 1 EYELAT = 26 ., DIREC = 280 ., SPEED = 13 ., EYPRES = 947.,  
RADIUS = 9 ., PFAR = 1016 ., SGW = 7 ., AN1 = 120.,

STEP 2 EYELAT = 26 ., DIREC = 280 ., SPEED = 13 ., EYPRES = 943.,  
RADIUS = 9 ., PFAR = 1016 ., SGW = 7 ., AN1 = 120.,

STEP 3 EYELAT = 27 ., DIREC = 295 ., SPEED = 13 ., EYPRES = 948.,  
RADIUS = 12 ., PFAR = 1016 ., SGW = 8 ., AN1 = 125.,

STEP 4 EYELAT = 28 ., DIREC = 295 ., SPEED = 13 ., EYPRES = 944.,  
RADIUS = 15 ., PFAR = 1016 ., SGW = 9 ., AN1 = 125.,

STEP 5 EYELAT = 28 ., DIREC = 305 ., SPEED = 11 ., EYPRES = 932.,  
RADIUS = 15 ., PFAR = 1016 ., SGW = 11 ., AN1 = 125.,

STEP 6 EYELAT = 29 ., DIREC = 320 ., SPEED = 10 ., EYPRES = 936.,  
RADIUS = 15 ., PFAR = 1016 ., SGW = 9 ., AN1 = 140.,

STEP 7 EYELAT = 30 ., DIREC = 340 ., SPEED = 9 ., EYPRES = 958.,  
RADIUS = 15 ., PFAR = 1016 ., SGW = 8 ., AN1 = 155.,

STEP 8 EYELAT = 30 ., DIREC = 355 ., SPEED = 9 ., EYPRES = 973.,  
RADIUS = 15 ., PFAR = 1016 ., SGW = 8 ., AN1 = 160.,

STEP 9 EYELAT = 30 ., DIREC = 5 ., SPEED = 8 ., EYPRES = 982.,  
RADIUS = 15 ., PFAR = 1016 ., SGW = 8 ., AN1 = 170.,

STEP 10 EYELAT = 31 ., DIREC = 5 ., SPEED = 8 ., EYPRES = 990.,  
RADIUS = 16 ., PFAR = 1016 ., SGW = 8 ., AN1 = 175 .,

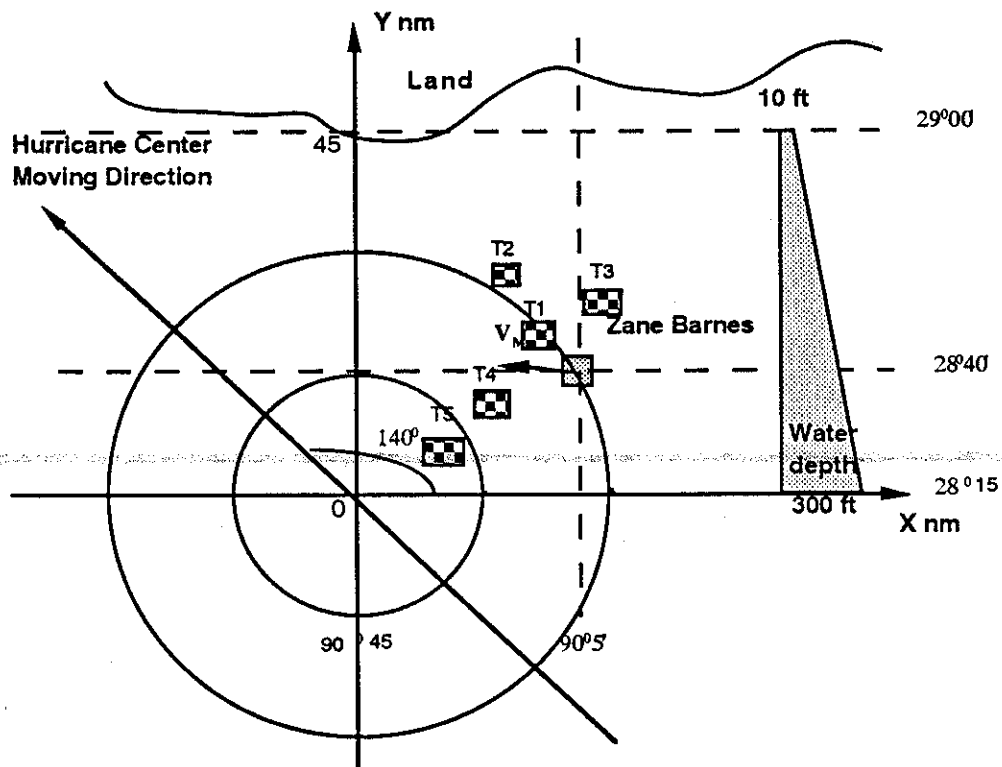
Storm Track Table

| STEP | LAT   | LONG   | SNAP | ROT | (YMDH)   |
|------|-------|--------|------|-----|----------|
| 1    | 25 36 | -81 12 | 1    | 0   | 92082412 |
| 2    | 25 41 | -82 10 |      | 0   | 2415     |
| 3    | 25 46 | -83 09 | 1    | 0   | 2418     |
| 4    | 26 00 | -84 03 |      | 0   | 2421     |
| 5    | 26 08 | -85 02 | 2    | 0   | 2500     |
| 6    | 26 23 | -85 54 |      | 0   | 2503     |
| 7    | 26 38 | -86 47 |      | 0   | 2506     |
| 8    | 26 56 | -87 38 | 3    | 0   | 2509     |
| 9    | 27 16 | -88 24 |      | 0   | 2512     |
| 10   | 27 31 | -89 08 | 4    | 0   | 2515     |
| 11   | 27 47 | -89 42 | 5    | 0   | 2518     |
| 12   | 28 10 | -90 09 | 5    | 0   | 2521     |
| 13   | 28 33 | -90 39 |      | 0   | 2600     |
| 14   | 28 47 | -91 03 | 6    | 0   | 2603     |
| 15   | 29 09 | -91 19 |      | 0   | 2606     |
| 16   | 29 37 | -91 34 | 7    | 0   | 2609     |
| 17   | 30 06 | -91 42 | 8    | 0   | 2612     |
| 18   | 30 29 | -91 40 | 9    | 0   | 2615     |
| 19   | 30 54 | -91 36 | 10   | 0   | 2618     |

Figure 7.2 Storm Parameters for Hurricane Andrew







**Fig. 7.3 Reference Frame in Andrew**

# Mooring Capacity 2300 kips

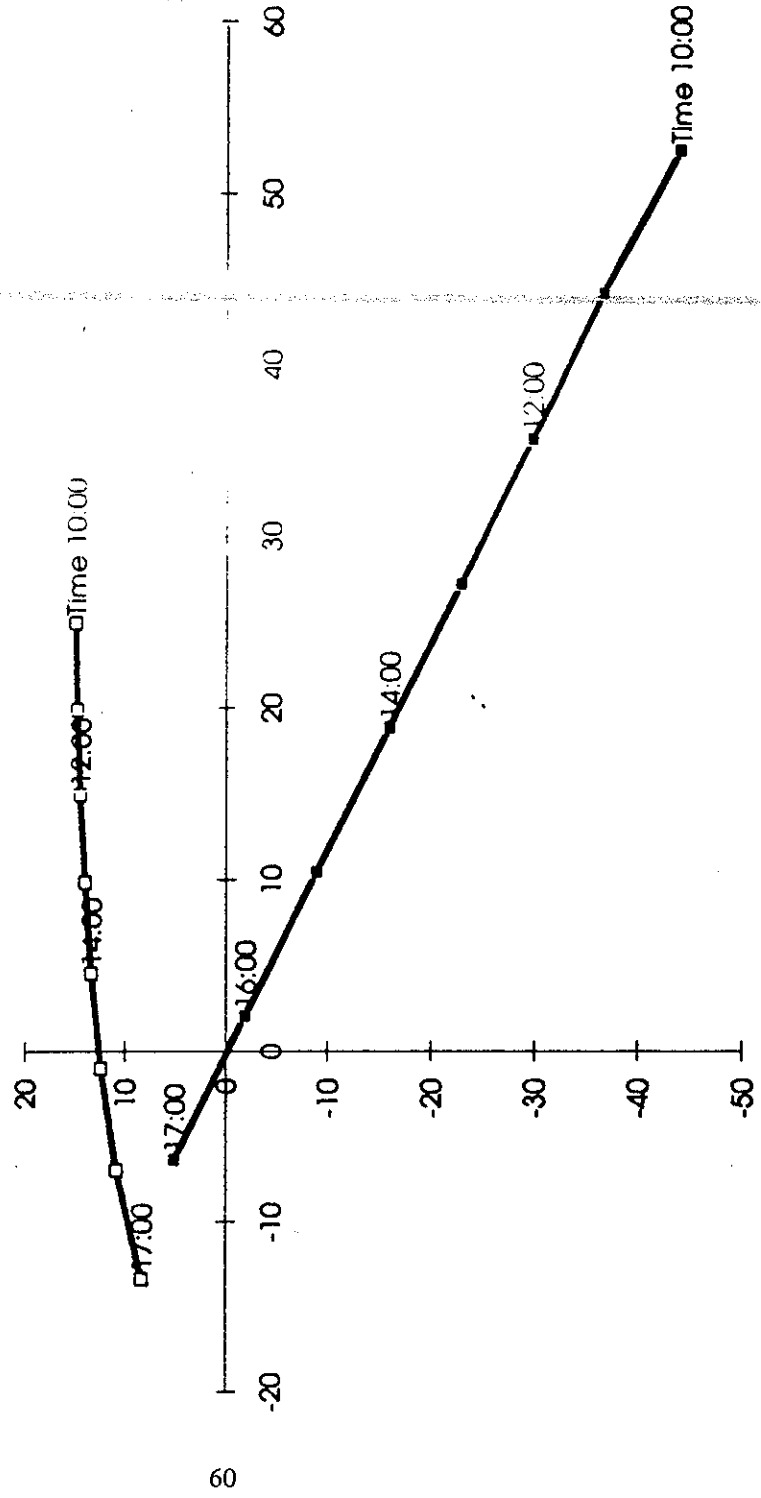


Figure 7.4a Moving Route of Zane Barnes in Andrew (Mooring Capacity 2300kips)

# Mooring Capacity 3000 kips

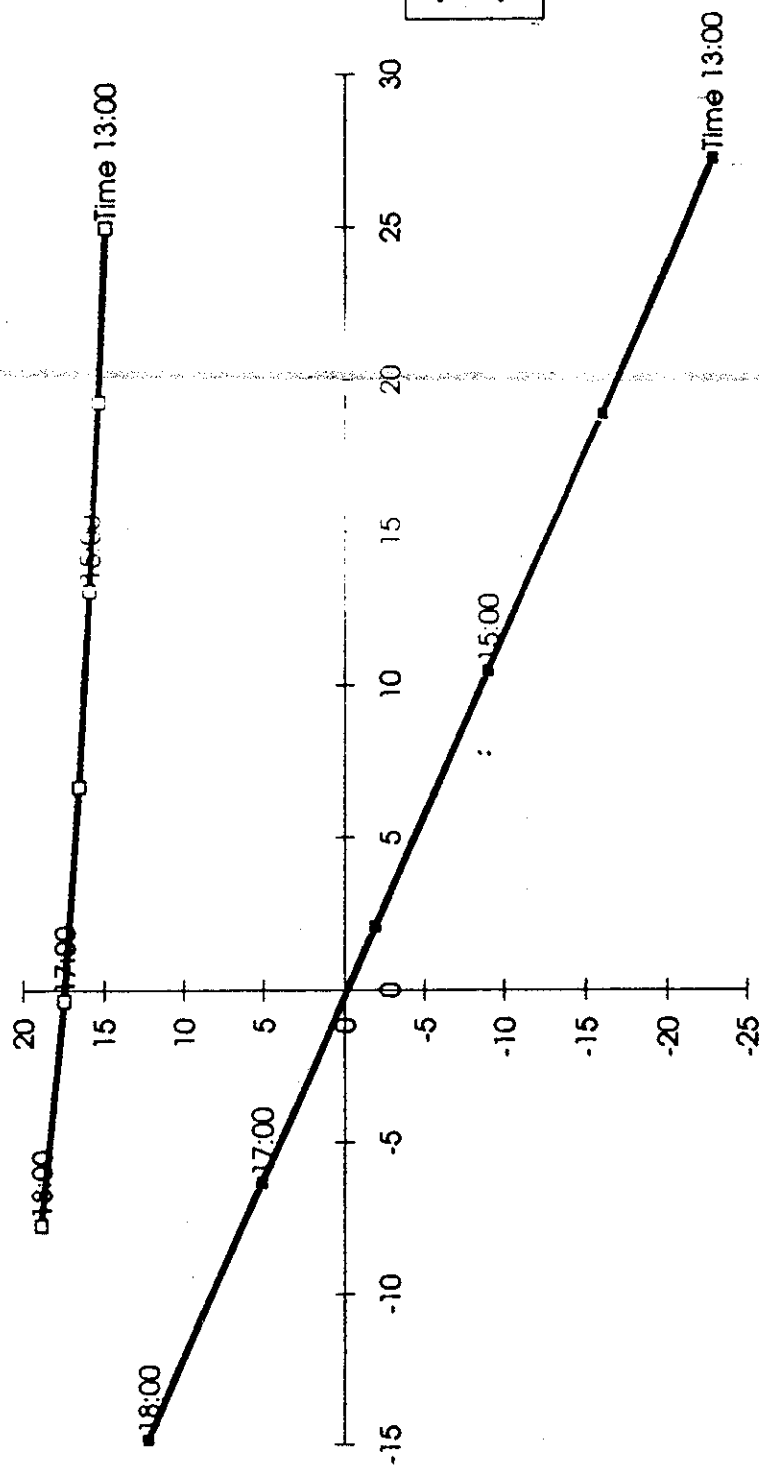


Figure 7.4b Moving Route of Zane Barnes in Andrew (Mooring Capacity 3000kips)

# Mooring Capacity 4000 kips

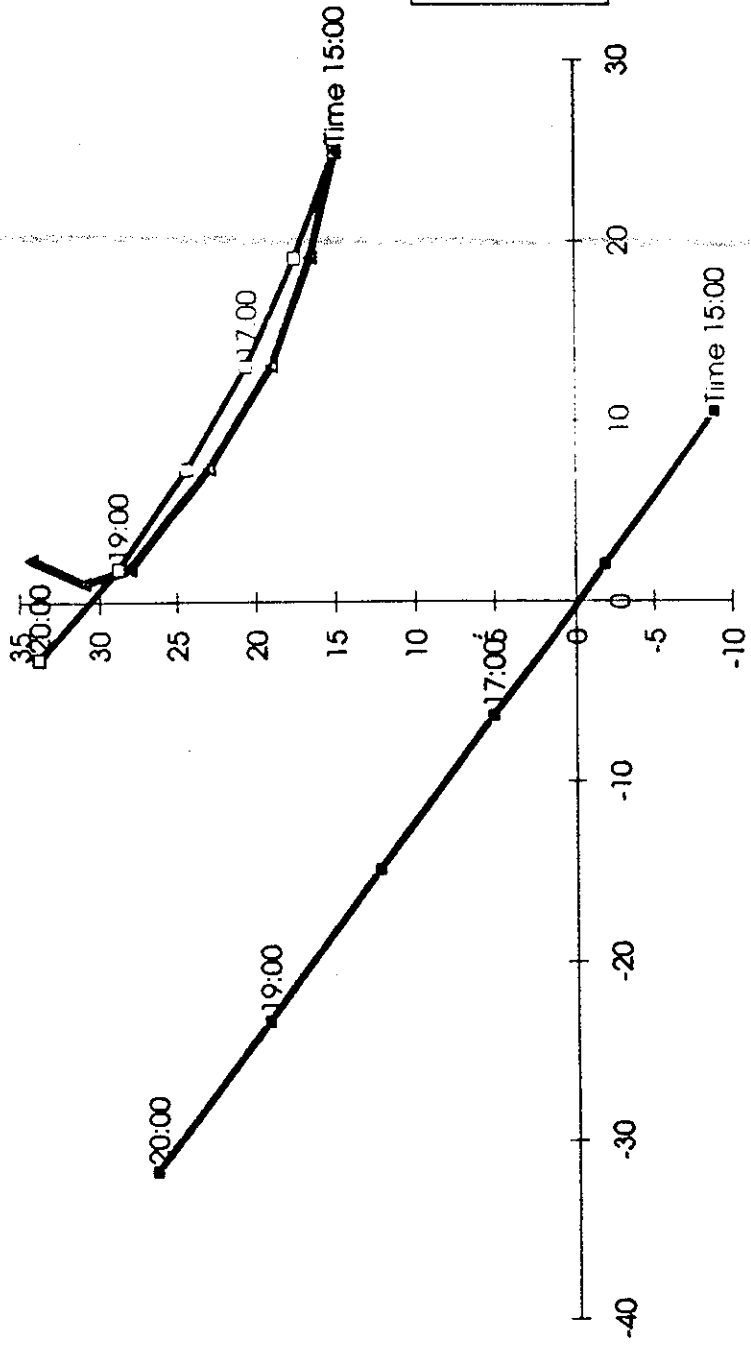
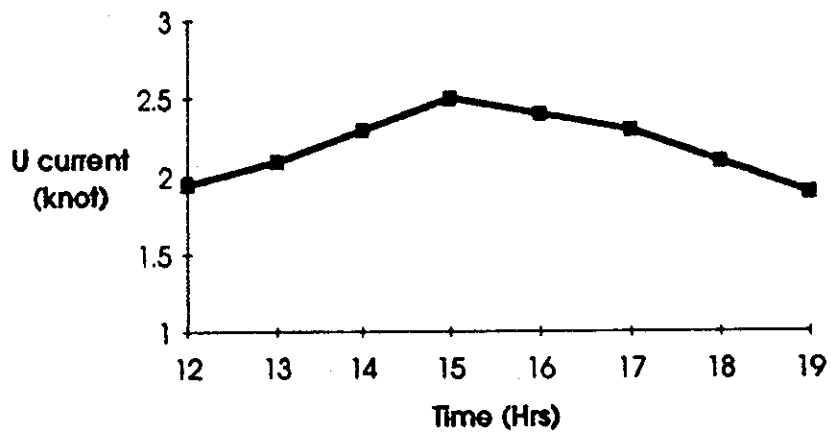
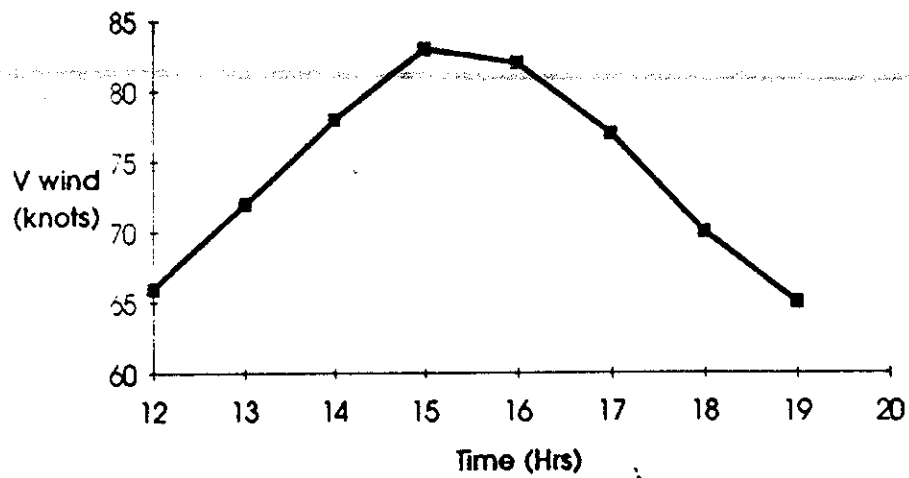
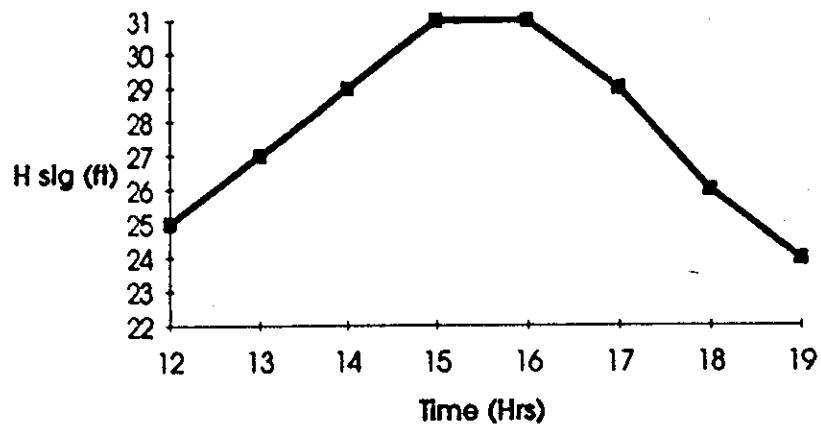
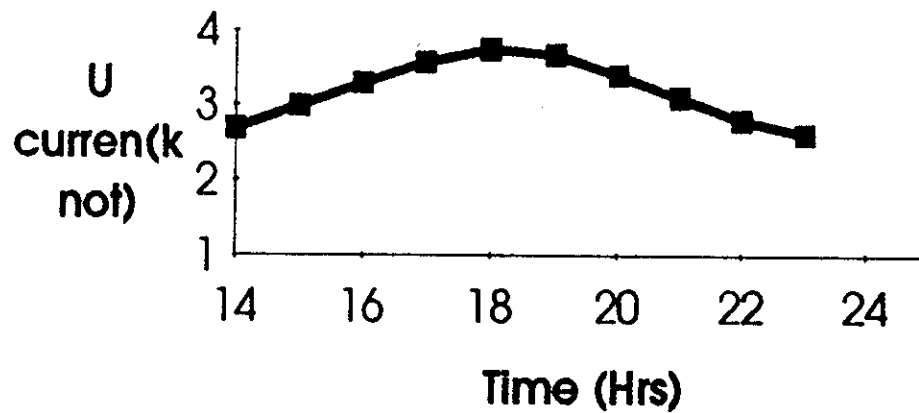
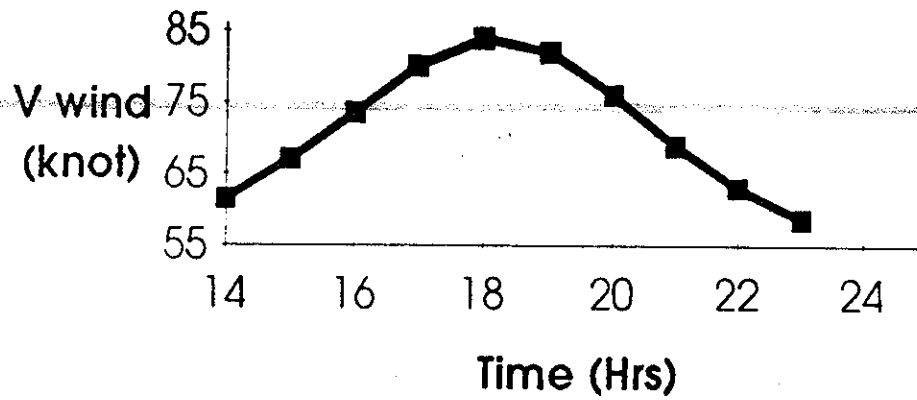
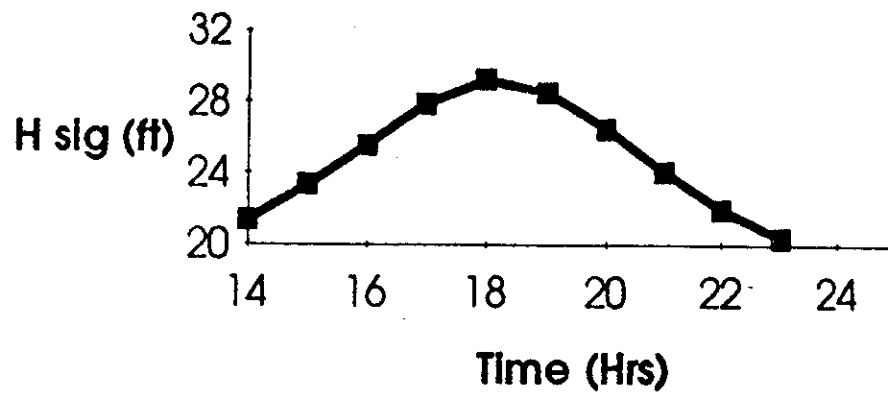


Figure 7.4c Moving Route of Zane Barnes in Andrew (Mooring Capacity 4000kips)



Time Histories of Conditions at Block GI(87) (Depth 170ft)

Figure 7.4d Environmental Time Histories of Conditions at Block GI(87) (Depth 170ft)



Time Histories of Conditions at Block ST(32) (Depth 54ft)

Figure 7.4e Environmental Time Histories of Conditions at Block ST(32) (Depth 54ft)

# **MODU: Zane Barnes**

| Location |      | Mooring  |      | Probability | Target Collision Probability % |      |      |      |      | Moor |
|----------|------|----------|------|-------------|--------------------------------|------|------|------|------|------|
| X nm     | Y nm | Mean kip | Mode | P %         | Tar1                           | Tar2 | Tar3 | Tar4 | Tar5 | M %  |
| 40       | 28   | 2500     | 8--8 | <b>4.38</b> | 1.02                           | 0.06 | 0    | 2.9  | 0.36 | 9    |
| 40       | 28   | 3500     | 8--8 | <b>3.96</b> | 1.92                           | 0.03 | 0.06 | 1.77 | 0.12 | 8.35 |
| 40       | 28   | 4500     | 8--8 | <b>2.76</b> | 1.56                           | 0    | 0.18 | 1.02 | 0    | 6    |
| 40       | 28   | 3500     | 8--6 | <b>2.2</b>  | 1.8                            | 0    | 0    | 0.42 | 0    | 5.8  |
| 40       | 18   | 2500     | 8--8 | <b>2.16</b> | 0.06                           | 0.12 | 0    | 0.6  | 0.9  | 10   |
| 40       | 18   | 3500     | 8--8 | <b>2.1</b>  | 0.42                           | 0.24 | 0.06 | 0.78 | 0.48 | 9    |
| 40       | 18   | 4500     | 8--8 | <b>1.32</b> | 0.24                           | 0    | 0.06 | 0.54 | 0.24 | 6    |
| 40       | 18   | 3500     | 8--6 | <b>0.54</b> | 0.3                            | 0.06 | 0    | 0.18 | 0    | 9    |
| 50       | 28   | 2500     | 8--8 | <b>4.8</b>  | 1.32                           | 0.24 | 0.6  | 1.8  | 0.72 | 12   |
| 50       | 28   | 3500     | 8--8 | <b>2.82</b> | 1.2                            | 0.3  | 0.48 | 0.04 | 0.18 | 7.6  |
| 50       | 28   | 4500     | 8--8 | <b>2.34</b> | 0.6                            | 0.3  | 1.02 | 0.24 | 0    | 6.5  |
| 50       | 28   | 3500     | 8--6 | <b>1.14</b> | 0.48                           | 0.06 | 0.48 | 0.06 | 0    | 9    |
| 50       | 18   | 2500     | 8--8 | <b>2.28</b> | 0.54                           | 0.18 | 0.06 | 0.72 | 0.3  | 10   |
| 50       | 18   | 3500     | 8--8 | <b>2.1</b>  | 0.36                           | 0.18 | 0.3  | 0.42 | 0.48 | 9    |
| 50       | 18   | 4500     | 8--8 | <b>1.32</b> | 0.24                           | 0.06 | 0.42 | 0.24 | 0.18 | 7    |
| 50       | 18   | 3500     | 8--6 | <b>0.36</b> | 0.18                           | 0.06 | 0.06 | 0    | 0    | 9    |

**Figure 7.5 Probability of Collision of Zane Barnes**



## Chapter 8. Conclusion and Recommendation

Considering the preliminary nature of this paper, few concrete conclusions can be draw. However, a MODU moving model is developed to predict the MODU's moving in the Gulf of Mexico during hurricanes. A Monte-Carlo simulation model is also developed to predict the probability of collision between MODUs and large facilities. The variability of hurricane parameters and their correlation, the storm spatial geometry, the shallow water shoaling effect, and modeling and parameter estimation uncertainties are considered. At last, the Zane Barnes, Zapata, Saratoga and Treasure 75, which all moved a significant distance during hurricane Andrew, were chosen to verify the simulation model. The simulation results matched closely to the information on the performance of the semi-submersible MODUs during hurricane Andrew. Also, the probability of collision between the MODU and surrounding structures is determined

Several assumptions and simplifications in the existing simulation model warrant improvement to increase the accuracy and utility of the results. Six improvements and additional studies are discussed in the following paragraphs:

- 1) The hurricane has been assumed to be a storm traveling along a straight line and changes in the storm parameters after shelf edge crossing are not considered, i.e., the intensity of the hurricane is assumed to be stationary during passage over the continental shelf. In fact, the hurricane route is generally curved. Based on the statistical analysis on the hurricane history, one can determine the parameters which influence changes of hurricane's direction, and determine their probability distribution. For example, one can define  $\alpha$  as the change in the hurricane direction per unit time and determine the probability distribution of  $\alpha$ . It is proposed to randomly change the hurricane direction according to a distribution function.

- 2) During hurricane Andrew, the Zane Barnes collided with several platforms after breaking loose from it location. From past experience, we know that the MODU drift direction

may have great change after the first collision, or may remain at the collision location for hours before it starts to drift again. It is proposed to develop a simulation of movements after an initial collision and how long MODUs stop and which direction they restart to drift.

3) Linear wave theory is used in the existing program to calculate the wave and current force on MODUs. It is proposed to update the force calculation algorithm based on higher order wave theory. This will be particularly important in shallow water - breaking wave conditions.

~~4) Parametric and sensitivity analyses will be performed to determine the important~~  
parameters which influence a MODU's probability of collision with surrounding large facilities. It is proposed to determine one or several critical parameters that have the most significant influence on the probability of collision.

5) It is proposed to study alternative practical and effective ways to reduce the probability of collision and collision effects. This will include study of the strategy of siting MODUs in areas where they will do the least harm in hurricanes. This will include study of alternative mooring systems and capacities. This will include study of alternative "fuses" in the mooring system; anchor line breaks versus anchor drags.

6) It is proposed to update the analytical and simulation model to include analysis of the movements of bottom-founded MODUs. This will include MODU sliding and skipping (hull raised by waves, MODU moves forward and then is dropped to the sea floor).

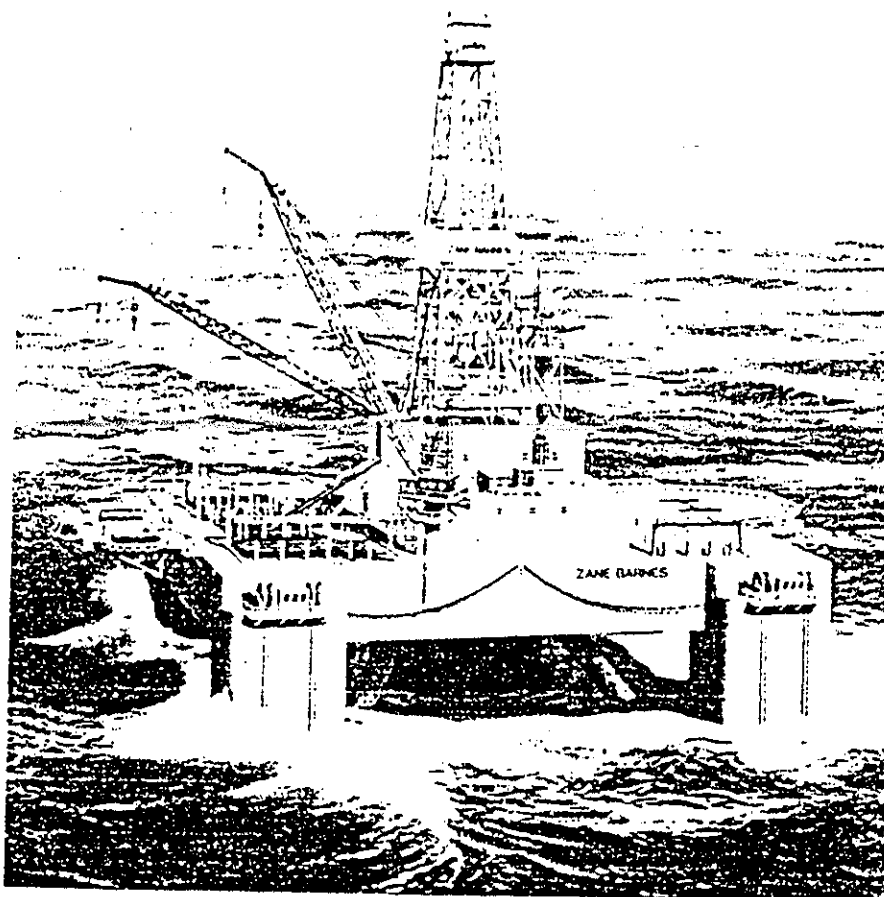
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### GENERAL

|                 |  |
|-----------------|--|
| Name            | Zane Barnes  |
| Owner           | Reading & Bates Drilling Company   |
| Manager         | Reading & Bates Drilling Company   |
| Year/yard built | 1986, by Ishikawajima-Harima Heavy Industries Co. Ltd., Aichi, Japan     |
| Design          | Friede & Goldman L-1020 Trendsetter, propulsion assisted semisubmersible |



### REGULATORY

|                |                                       |
|----------------|---------------------------------------|
| Registration   | U.S.A.                                |
| Classification | ABS                                   |
| Approvals      | US Coast Guard; UK DOE; IMO; NMD; CCG |

### PRINCIPLE DIMENSIONS

|                     |   |
|---------------------|---|
| Length overall      | 370 ft.   |
| Width overall       | 255 ft. (excl. anchor racks)  |
| Height to main deck | 140 ft.   |
| Deck area           | Approx. 50,625 ft <sup>2</sup> (upper hull dimensions 225 ft x 225 ft x 25 ft deep; open deck space (excl. heliport) 15,000 ft <sup>2</sup> ) |
| Moon pool           | 28 ft diameter at top, 38 ft diameter at bottom   |
| Columns             | 4 x corner caissons, 45 ft across flats; transverse spacing 180 ft c-c; longitudinal spacing 185 ft c-c; centre caisson 72 ft diameter        |
| Pontoons            | 2 x 370 ft at 45 ft beam amidships x 60 ft beam at ends x 30 ft deep amidships x 40 ft deep at ends   |

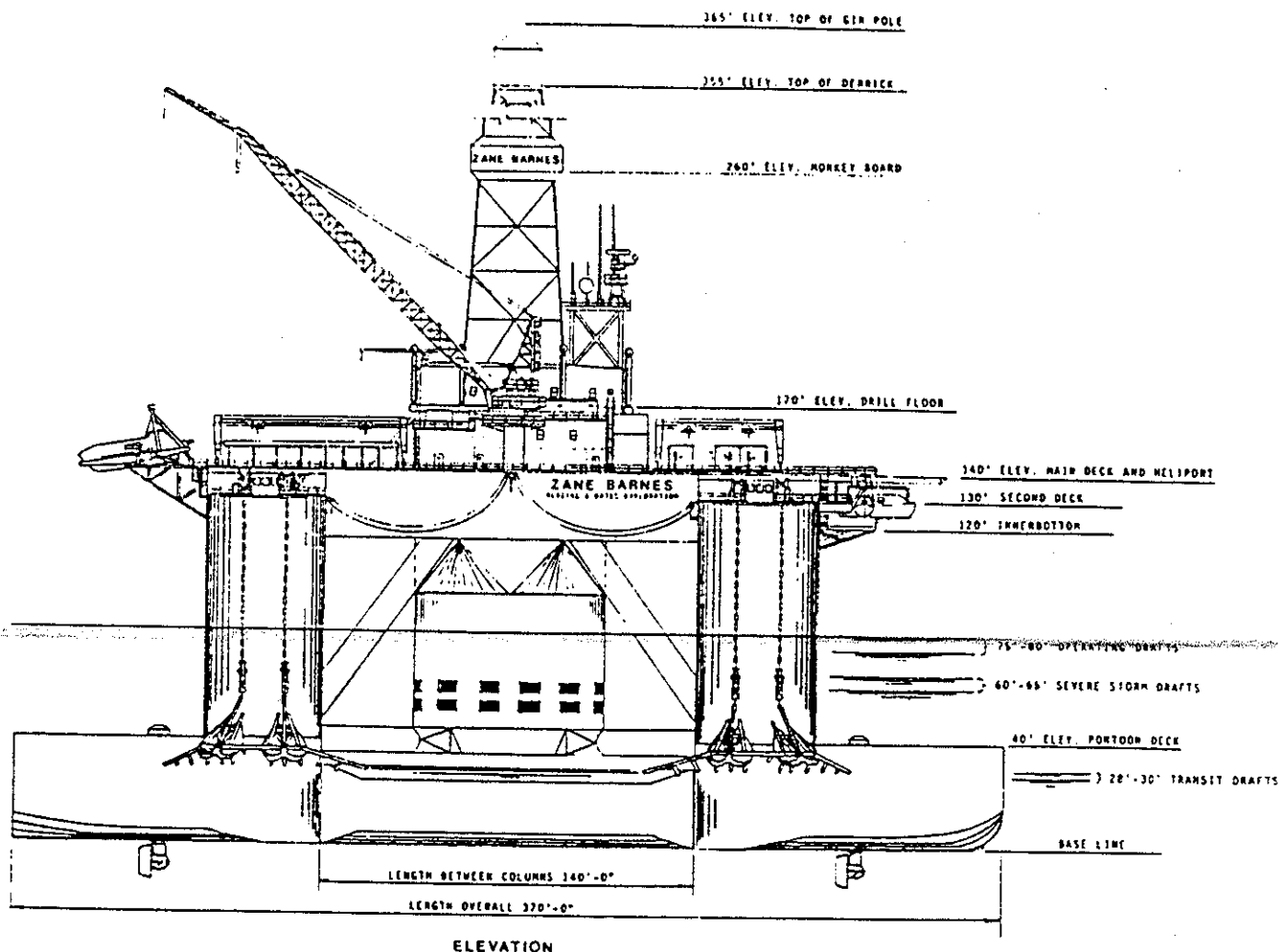
### POWER/PROPULSION

|                     |   |
|---------------------|---|
| Main power plant    | 2 x Wärtsila 12V32; 2 x Wärtsila 8R32   |
| Generators          | 2 x Stromberg HSPTL-15-855; 2 x Stromberg HSPTL-15-855  |
| Power distribution  | Stromberg 6.9 KV medium voltage system with Ross-Hill SCR system  |
| Emergency power     | Wärtsila LR32D diesel generator set, 1480 KW  |
| Propulsion          | 2 x 5500 hp azimuth thrusters, variable pitch/speed; provision for DP with two additional 5500 hp azimuth thrusters |
| Towing requirements | Varies with location  |

### DRAFT/DISPLACEMENT

|                        |                              |
|------------------------|------------------------------|
| Operating draft        | 75-80 ft.; air gap 35-40 ft. |
| Transit draft          | 28-30 ft.; air gap 85-87 ft. |
| Survival draft         | 60-65 ft.; air gap 50-55 ft. |
| Operating displacement | 50,715-52,311 LT             |
| Transit displacement   | 29,376-31,434 LT             |

# Zane Barnes (cont'd)



ELEVATION

## OPERATING PARAMETERS

|                        |   |
|------------------------|---|
| Maximum water depth    | 5000 ft.  |
| Maximum drilling depth | 30,000 ft.  |
| Transit speed          | Excess of 8 knots   |
| Survival criteria      | Maximum survival storm with 5000 LT variable deck load; wind, 1 min. mean, 100 knots; current nil; 60 ft significant wave height, 110 ft maximum; average period 12.9 seconds                                   |
| Drilling capability    | Maximum drilling with 5000 LT variable deck load; wind, 1 min. mean, 60 knots; surface current 3 knots; current at 1500 ft WD, 1 knot; significant wave height 30 ft, maximum 60 ft; average period 9.7 seconds |
| Design temperature     | -20 deg C   |

## CAPACITIES

|                        |   |
|------------------------|---|
| Variable deck load     | Minimum variable deck & column load 5000 LT (drilling/storm/transit)  |
| Substructure loads     | Setback 500,000 lbs; rotary 1,600,000 lbs; riser tensioner load 2,000,000 lbs; max. design load 4,100,000 lbs   |
| Tubulars in pipe racks | 12,500 ft <sup>2</sup> with 30-ton gantry crane service   |
| Liquid mud             | 4000 bbls   |
| Bulk mud & cement      | 29,000 ft <sup>3</sup>  |
| Sack materials         | 10,000 sacks  |
| Drilling water         | 21,000 bbls in lower hulls  |
| Potable water          | 100 bbls in upper hull; 3400 bbls in caissons   |
| Fuel oil               | 1100 bbls in upper hull; 37,350 bbls in lower hulls   |
| Chain/anchors          | Chain lockers sized for 4000 ft of chain  |
| Other                  | Cellar deck storage 3450 ft <sup>2</sup> ; lube oil 600 bbls; JP-5 42 bbls; liquid additive tanks 95 bbls; seawater ballast 48,900 bbls in caissons, 151,400 bbls in lower hulls; clean mud oil 8500 bbls |

## DRILLING EQUIPMENT

|                      |   |
|----------------------|---|
| Derrick              | 185 ft high, 40 ft x 40 ft base, static hook load 2,000,000 lbs   |
| Drawworks            | 3000 hp   |
| Rotary               | 49 1/2"   |
| Top drive            | Provision for top drive system  |
| Pipe handling system | Mechanical pipe ramp handling system located on the aft deck; upper and lower racker arms; iron roughneck |
| Motion compensator   | Western Gear, 600,000 lbs capacity; capacity latched or rod fully extended 1,600,000 lbs; 25 ft stroke    |
| Riser tensioners     | 6 x dual tensioners, total 1,200,000 lbs x 50 ft stroke; provision for two additional tensioners          |
| Guideline tensioners | Guidelineless BOP system  |
| Cementing unit       | Halliburton SKF-J Twin HT-300   |

## MODUSIM 2.0 USER MANUAL

### Part 1. INSTALLATION

#### 1.1 Backup Disk

Before any installation begins, it is always a good practice to backup the program diskette in the back of the report. We assume you are already familiar with DOS commands or Windows operation. For example, in DOS you will need the DISKCOPY command to make backup copies of your program disk.

#### 1.2 System Requirements

To run MODUSIM 2.0, you must have a 386 or 486 based PC with 2MB RAM at least, MS DOS 5.0, Windows 3.0, EXCEL 4.0 and @RISK 3.0. A math co-processor chip is recommended for a 386 based PC, 486 based PCs come with one.

#### 1.3 Installation

To install MODUSIM 2.0, first copy all the files in the attached disk to your hard drive under the directory "c:\MODUSIM". Then you can open the file 'MODU.XLW' directly from EXCEL4.0 & @Risk3.0. Or you can specify the program group name, item name, and the path of MODUSIM to windows. Type WIN to execute Windows, select New from File menu in program Manager to add the program group. The following window will appear, select Program Group and then OK.

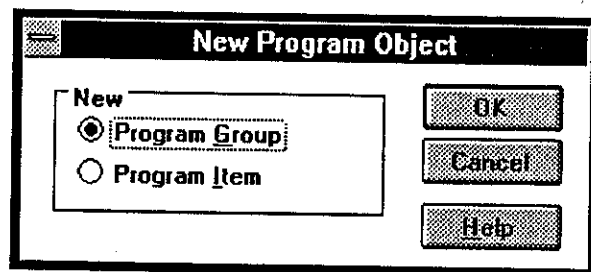
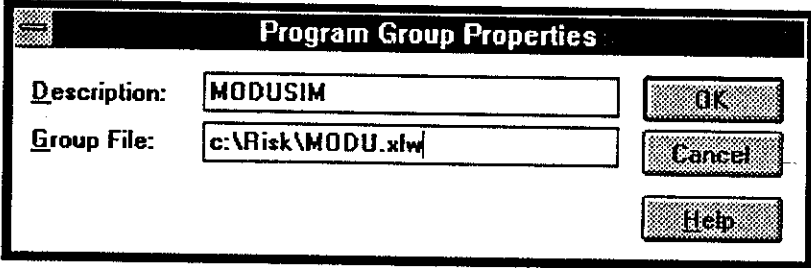


Figure 1.1: Select 'Program Group' for the MODUSIM Program.

Next the following window will appear. Fill in the Description and Group File as indicated. Then select OK.



The image shows a Windows-style dialog box titled "Program Group Properties". It has two text input fields. The first field is labeled "Description:" and contains the text "MODUSIM". The second field is labeled "Group File:" and contains the text "c:\Risk\MODU.xlw". To the right of these fields are three buttons: "OK", "Cancel", and "Help".

**Figure A.1.2: Specify the Group Name and the Filename and Path**

Notice that a new program group **MODUSIM** has been created in your Microsoft Windows. Now you can double click the icon to start MODUSIM.



## Part 2. USING MODUSIM 2.0

After double clicking the **MODUSIM** icon, the main window will pop up like the following Figure 2.1. The menu bar is similar to that of EXCEL 4.0, except an extra MODUSIM menu at the end of it. MODUSIM has 18 functions, as in Figure 2.2. Those users who are not familiar with windows operation are recommended to following the step-by-step directions in this chapter. Here, for example, let's say we have a MODU named "Zane Barnes".

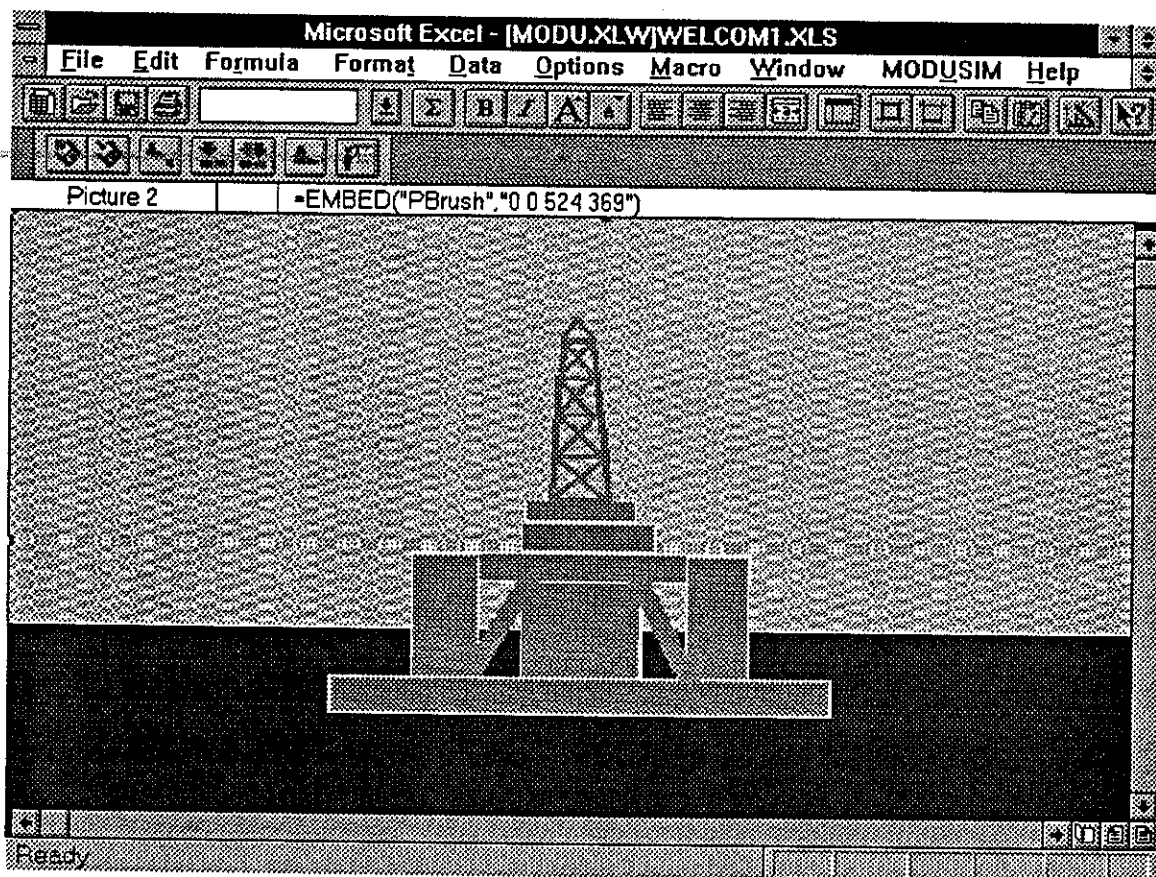


Figure A.2.1 MODUSIM is Popped Up

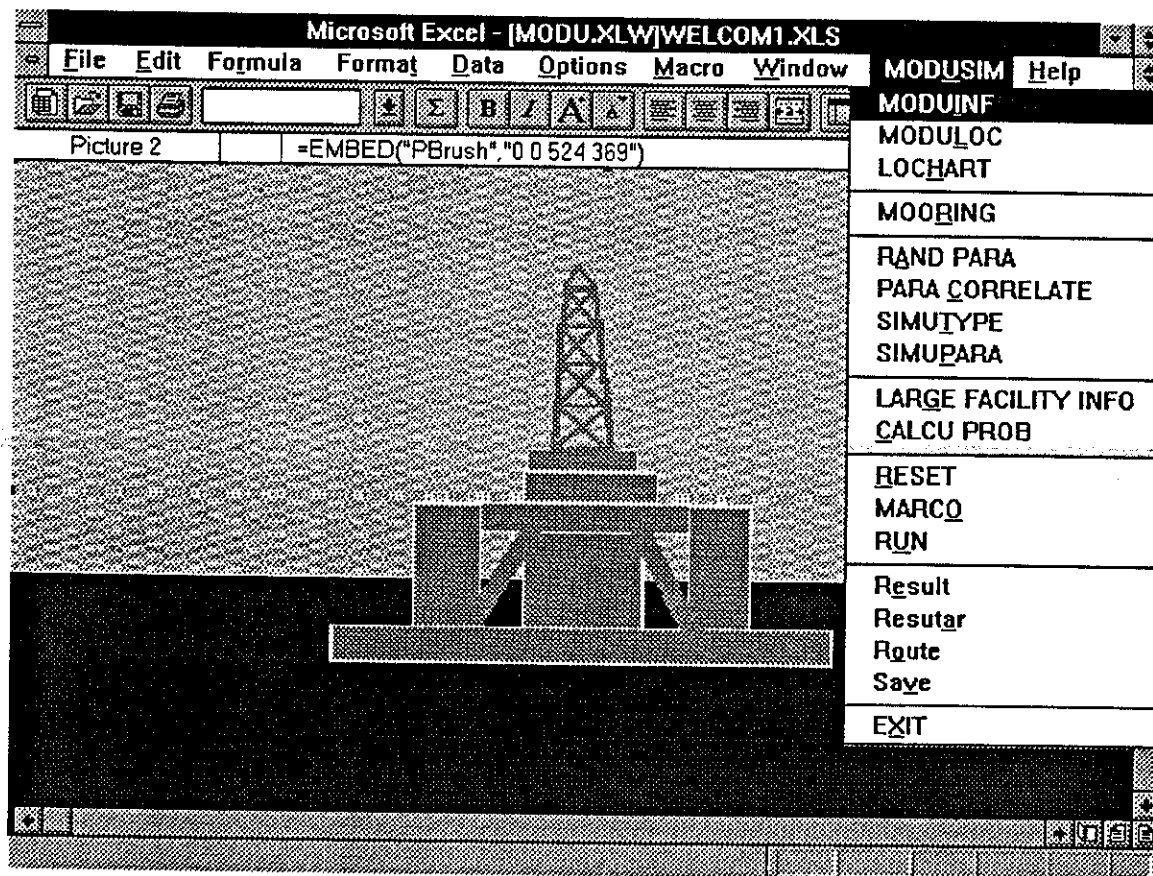


Figure A.2.2 Function in MODUSIM Menu

## 2.1 MODUINF Command

**MODUINF** command allows to input the MODU's general information. The dialogue box 'MODU INFORMATION' will pop up when **MODUINF** command is selected.

**MODU INFORMATION**

? MODU NAME: ZANE BARNES OK Cancel

**MODU PARAMETERS**

|  |       |
|--|-------|
| DISPLACEMENT (LT):                       | 50715 |
| DRAFT (FT):                              | 60    |
| DIAMETER OF CORNER CAISSON (FT):         | 45    |
| DIAMETER OF CENTRE CAISSON (FT):         | 72    |
| LENGTH OF PONTON (FT):                   | 370   |
| HEIGHT OF PONTON (FT):                   | 40    |
| WIDTH OF PONTON (FT):                    | 20    |
| EQUIVALENT WIND AREA (FT <sup>2</sup> ): | 25000 |

Figure A.2.3 Input MODU General Information

To input the information, you can click on the certain box with mouse or type 'ALT' + 'Underline letter'. For example, to input **DISPLACEMENT**, type ALT+D. When you finished, click **OK**, or you can click **Cancel** to cancel the dialogue.

## 2.2 MODULOC Command

**MODULOC** command allows to input coordinates of MODU's initial location. When **MODULOC** command is selected, the dialogue box 'MODU LOCATION' will pop up.

| MODU LOCATION                                    |                                    |
|--|------------------------------------|
| <b>INPUT TYPE</b>                                |                                    |
| <input checked="" type="radio"/> <b>KEYBOARD</b> | <input type="radio"/> <b>CHART</b> |
| <b>OK</b> <b>Cancel</b>                          |                                    |
| <b>KEYBOARD</b>                                  | <b>CHART</b>                       |
| X COORDINATE (NM): 40                            | X COORDINATE (NM): 40.1            |
| Y COORDINATE (NM): 28                            | Y COORDINATE (NM): 18              |
| WATER DEPTH (FT): 170                            | WATER DEPTH (FT): 240.833333       |
| DIST TO LAND (NM): 52                            | DIST TO LAND (NM): 52              |

Figure A.2.4 Input MODU Initial Location

In the group of **Input Type**, if **Keyboard** is selected, the information will be input from keyboard to the box in the group of **keyboard**. The input information includes X, Y coordinates, water depth of MODU location and the distance from X-axis to coast. If **Chart** is selected, next command **LOCHART** need to be selected to input information from chart. It is recommended that **Keyboard** function is used to input the initial location and **Chart** function is used to change the location of MODU.

### 2.3 LOCHART Command

If **Chart** was selected in the **MODULOC** command, **LOCHART** command need to be selected, and the chart 'MODU Moving Route' will pop up. To change the location of the MODU, click on the MODU while hold down **CTRL**, then drag MODU to wherever you want it to be sited.

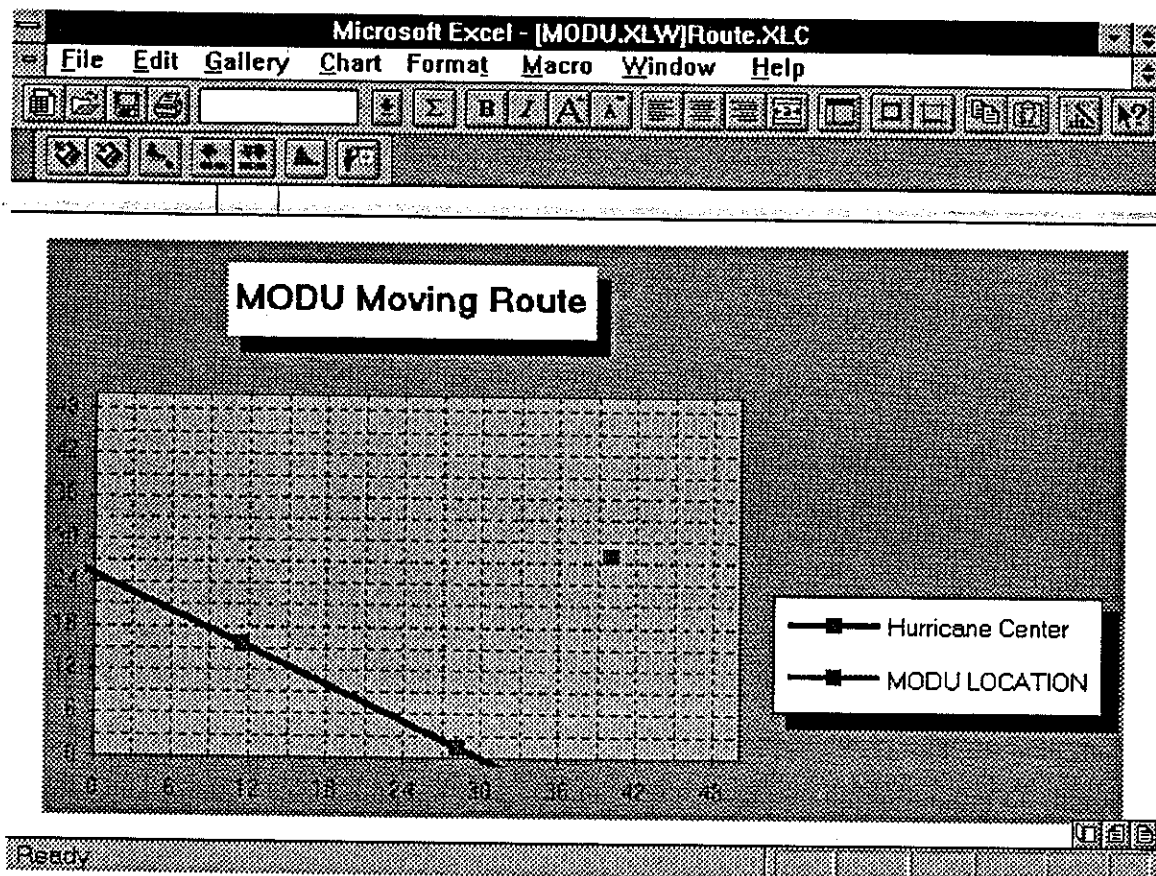


Figure A.2.5 Initial Location of MODU

## 2.4 Mooring Command

**Mooring** Command allows to input mooring system information. The dialogue box 'Mooring System' will pop up when Mooring command is selected.

**MOORING SYSTEM**

?

OK

Cancel

**MOORING CAPACITY**

MEAN VALUE (KIPS): 3500

STANDARD DEVIATION: 1000

**FAILURE MODE**

NUMBER OF MOORING LINES: 8

NUMBER OF BREAKING LINES: 8

DYNAMIC DRAGGING COEFF.: 0.5

Figure A.2.6 Input Mooring System Information

In the group of **MOORING CAPACITY**, input the mean value and standard deviation of mooring strength; in the group of **FAILURE MODE**, input the total number of mooring lines, number of broken lines while failure and the dynamic dragging coefficient of anchor while they are dragging in the bottom of the sea.

## 2.5 RAND PARA Command

RAND PARA command allows to input probability distributions of random parameters. The dialogue box 'RANDOM PARAMETER' will pop up when RAND PARA command is selected.

**RANDOM PARAMETER**

PN POISSON  
LAMBDA  
0.131

FI TRIANG (DEGREE)  
MINIMUM 0  
MOST LIKELY 101  
MAXIMUM 180

XD UNIFORM (NM)  
MINIMUM -20  
MAXIMUM 60

DP LOGNORM (MB)  
MEAN 53.64  
ST.D 16.14

RM LOGNORM (NM)  
MEAN 24.16  
ST.D 7.85

VF LOGNORM (KTS)  
MEAN 11.8  
ST.D 4.5

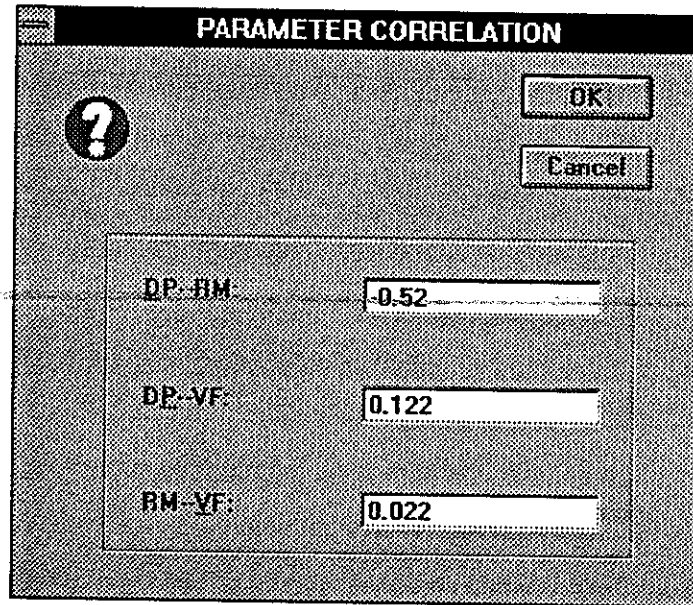
OK  
Cancel

Figure A.2.7 Input Random Parameter Information

Note here, Lamta is the hurricane occurrence rate at a point in the selected reference per year per nautical mile.

## 2.6 CORR CORRELATE Command

**CORR CORRELATE** command allows to input correlation among random parameters. The dialogue box 'PARAMETER CORRELATION' will pop up when it is selected.



The dialog box titled "PARAMETER CORRELATION" contains the following data:

| Parameter Pair | Correlation Coefficient |
|----------------|-------------------------|
| DP-BM          | 0.52                    |
| DP-VF          | 0.122                   |
| BM-VF          | 0.022                   |

Figure A.2.8 Input Correlation Coefficients among Random Parameters



## 2.7 SIMUTYPE Command

**SIMUTYPE** command allows to set up the simulation. The dialogue box 'SIMULATION TYPE' will pop up when **SIMUTYPE** is selected.

**SIMULATION TYPE**

**SIMULATION SETTING**

☒ MONTE-CARLO ☐ SPECIAL

**Monte-Carlo**

**SIMM NUMBER:**  
2500

**SIMM TYPE**

☒ 1 FAST ☐ 2 SLOW

☒ Detail Location

☒ Special Target

**SPECIAL HURRICANE PARAMETER**

**TRACKS CROSSING CONTOUR (NM):** 30

**TRACK DIRECTION (DEGREE):** 140

**PRESSURE DIFFERENCE (MB):** 81

**RADIUS OF MAXIMUM WIND SPEED (NM):** 10

**STORM FORWARD SPEED (KTS):** 11

OK Cancel

Figure A.2.9 Set Up the Simulation

In the group of **Simulation setting**, select **Monte-Carlo** to calculate the probability of collision, select **SPECIAL** to simulate the MODU's movement during a given hurricane.

In the group of **Monte-Carlo**, input the simulation number, select **1 FAST** in **SIMM TYPE**. The type **2 SLOW** will be discussed later. Check **Detail Location** to include the MODU information within target circles. Check **Special Target** to calculate the probability of collision within a given target.

If **SPECIAL** in **SIMULATION SETTING** was selected, the given hurricane parameters should be input in the group of **SPECIAL HURRICANE PARAMETER**.

## 2.8 SIMUPARA Command

**SIMUPARA** command allows to input calculation coefficients. The dialogue box 'SIMULATION PARAMETERS' will pop up when it is selected. Input the wind, wave and current force coefficients in **FORCE PARAMETERS**, Select the type of current velocity distribution in **CURRENT TYPE**, Select the time step between the re-calculation of environmental forces in **TIME STEP**.

**SIMULATION PARAMETERS**

**FORCE PARAMETERS**

WAVES

WIND

CURRENT

**CURRENT TYPE**

☒ DISTRIBUTION 1

☐ DISTRIBUTION 2

☐ DISTRIBUTION 3

**TIME STEP**

☐ 0.5 HOUR

☒ 1.0 HOUR

☐ 1.5 HOURS

☐ 2 HOURS

OK

Cancel

Figure A.2.10 Input Calculation Coefficients

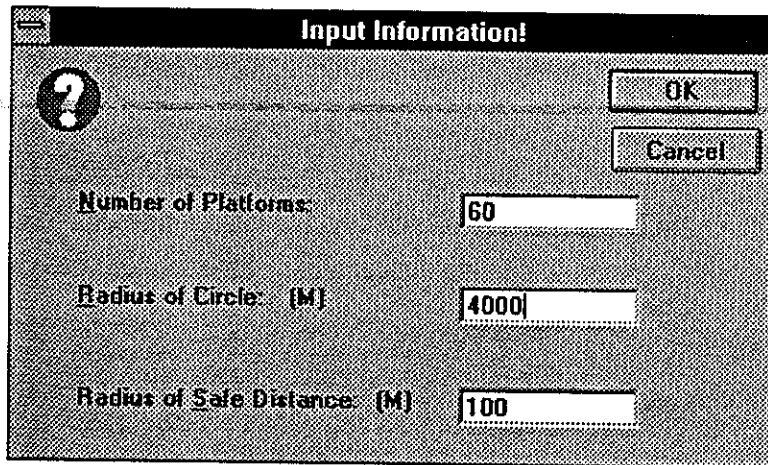
## 2.9 LARGE FACILITY INFO Command

**LARGE FACILITY INFO** command allows to set up the simulation for probability of collision within target circles. 'LARGE FACILITY INFORMATION' dialogue box will pop up when it is selected.

**Number of Platforms:** Structure number within the target circle.

**Radius of Circle:** Radius of target circle

**Radius of safe Distance:** The safety distance between the MODU and structures.

A screenshot of a Windows-style dialog box titled "Input Information!". The dialog box has a question mark icon in the top-left corner. In the top-right corner, there are two buttons: "OK" and "Cancel". The main area of the dialog box contains three input fields. The first field is labeled "Number of Platforms:" and contains the value "60". The second field is labeled "Radius of Circle: (M)" and contains the value "4000". The third field is labeled "Radius of Safe Distance: (M)" and contains the value "100".

| Field Label                  | Value |
|------------------------------|-------|
| Number of Platforms:         | 60    |
| Radius of Circle: (M)        | 4000  |
| Radius of Safe Distance: (M) | 100   |

Figure A.2.11 Input Target Circle Information

Note here, the location of target circles is determined by the user from file [MODU.xlw]modu.xls. You can choose as many as 5 target circles.

## 2.10 CALCU PROB Command

**CALCU PROB** command allows to begin the simulation of collision within the target circle. When the simulation is completed, a dialogue box will pop up the calculation result. A pre-calculated curve about the probability of collision within the target circle with  $R=0.6$  to  $4.8$  nm is presented in Figure ##. For a target circle with given radius and number of structures, the probability of collision can be found from the curve.

### 2.11 RESET Command

**RESET** command allows to reset the program before each simulation.

### 2.12 MARCO Command

**MARCO** command allows to change active window to marco sheet.

### 2.13 RUN Command

**RUN** command is clicked to begin the simulation. Before click **RUN**, you should set up @RISK simulation parameters. The recommended @RISK simulation settings is as in Figure 2.12. After the simulation is completed, a dialogue box will pop up.

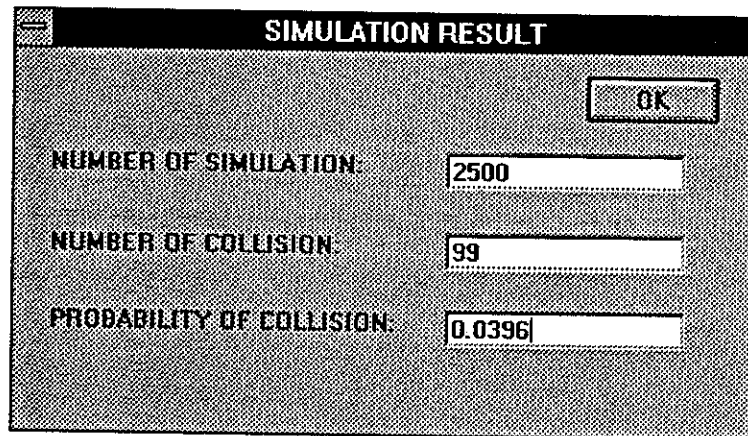
The image shows a dialog box titled "Simulation Settings" with various configuration options for an @Risk simulation. The settings are organized into several sections:

- Iterations:** # Iterations = 2500, # Simulations = 1. Buttons for OK and Cancel are on the right.
- Random Number:** Generator Seed = 0. Checkboxes for "Pause on Error" and "Update Display" are present.
- Sampling Type:** Radio buttons for "Latin Hypercube" (selected) and "Monte Carlo". A checkbox for "Collect Distribution Samples?" is checked.
- Standard Recalc:** Radio buttons for "Expected Value", "Monte Carlo" (selected), and "True EV".
- Convergence:** A checkbox for "Monitor Convergence?" is checked, with "Check Every" 100 Iterations. An "Auto-Stop Simulation?" checkbox is unchecked, with a sub-setting "Stop When All Output Perc% Change Less Than" 1.5 %.
- Execute Macro:** A checkbox for "Execute Macro?" is unchecked. Below it is a "Macro name:" text box. Radio buttons for when to execute the macro are: "Before simulation", "Before sampling/ worksheet recalc", "After sampling/ worksheet recalc", and "After simulation".

Figure A.2.12 @Risk Simulation Setting

## 2.14 RESULT Command

Click **RESULT** command for simulation result.



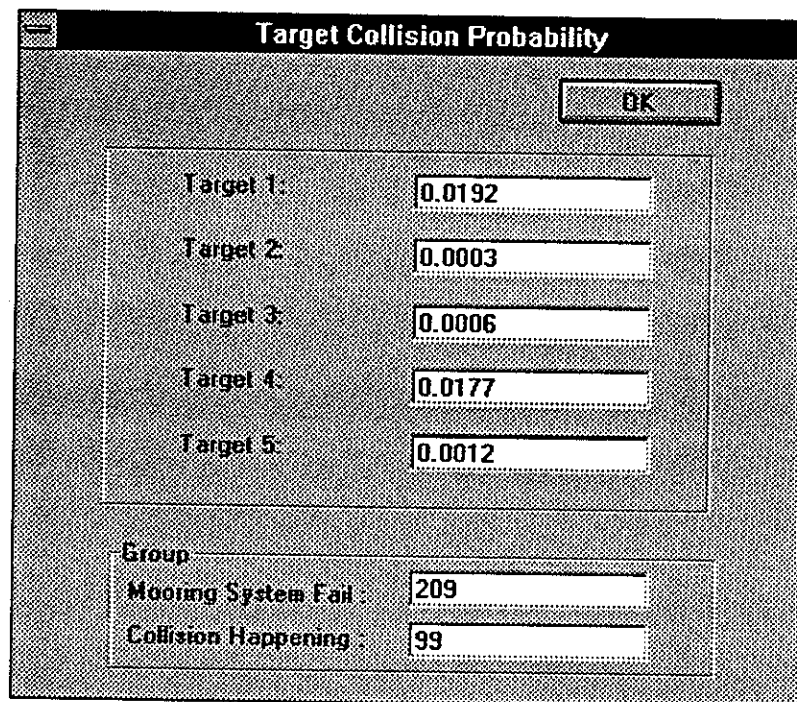
A dialog box titled "SIMULATION RESULT" with an "OK" button in the top right corner. It contains three rows of labels and text input fields:

| Label                     | Value  |
|---------------------------|--------|
| NUMBER OF SIMULATION:     | 2500   |
| NUMBER OF COLLISION:      | 99     |
| PROBABILITY OF COLLISION: | 0.0396 |

Figure A.2.13 Simulation Result

## 2.15 RESUTAR Command

Click **RESUTAR** for output of special target collision probability.



A dialog box titled "Target Collision Probability" with an "OK" button in the top right corner. It contains two sections of labels and text input fields:

| Label     | Value  |
|-----------|--------|
| Target 1: | 0.0192 |
| Target 2: | 0.0003 |
| Target 3: | 0.0006 |
| Target 4: | 0.0177 |
| Target 5: | 0.0012 |

| Label                 | Value |
|-----------------------|-------|
| Group                 |       |
| Mooring System Fail : | 209   |
| Collision Happening : | 99    |

Figure 2.14 Simulation Result for target Circles

## 2.16 ROUTE Command

In case of simulation the MODU's movement during a given hurricane, click **ROUTE** command to get the MODU's moving route during hurricanes. Here is Zane Barnes's moving route during hurricane Andrew.

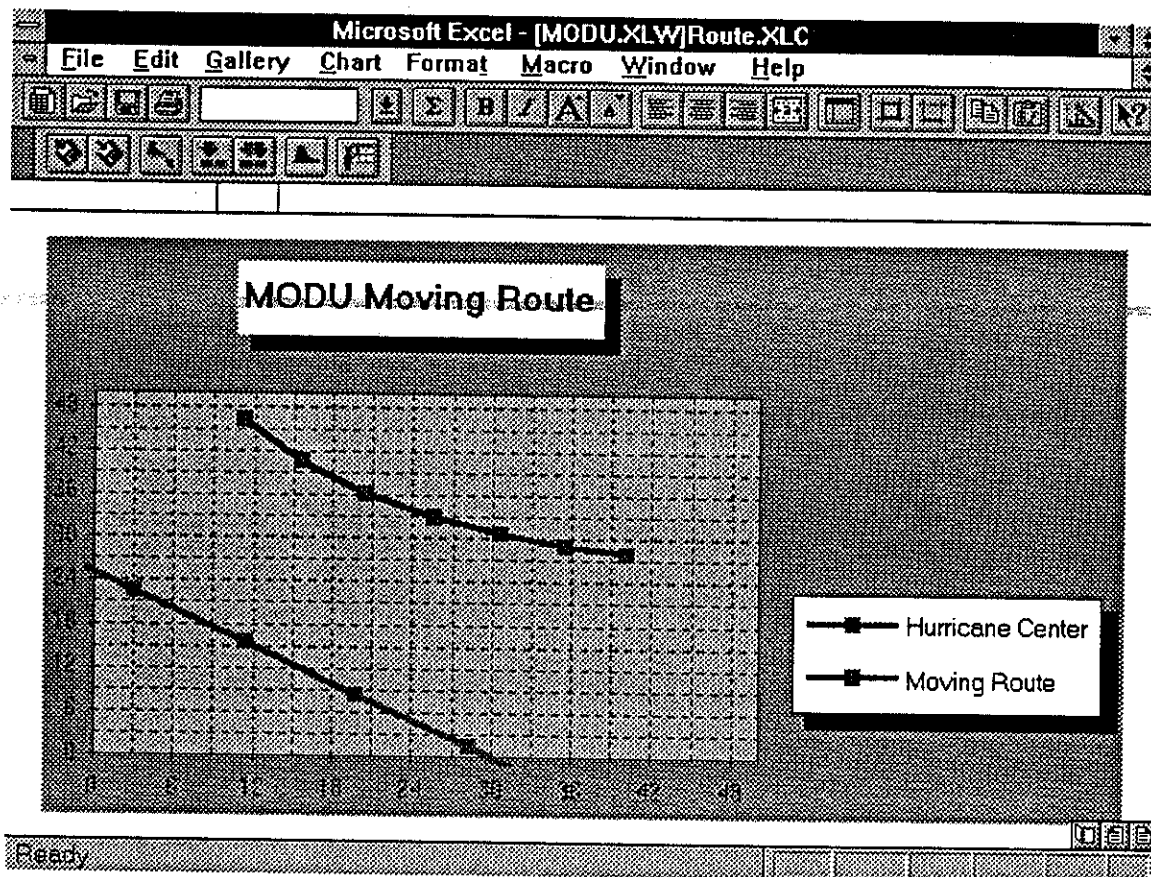


Figure A.2.15 Zane Barnes's moving Route during Hurricane Andrew

## 2.17 SAVE Command

To save simulation result as in Figure 2.16.

### SIMULATION RESULT

|                           |          |                  |          |              |         |
|---------------------------|----------|------------------|----------|--------------|---------|
| MODU NAME:                |          | ZANE BARNES      |          |              |         |
|                           |          |                  |          |              |         |
| LOCATION:                 |          | MOORING CAPACITY |          | FAILURE MODE |         |
| X                         | Y        | MEAN             | ST.D     | NOM          | NOB     |
| 50                        | 28.1     | 3500             | 1000     | 8            | 6       |
|                           |          |                  |          |              |         |
| Probability of collision: |          |                  | 0.0114   |              |         |
| Target 1                  | Target 2 | Target 3         | Target 4 | Target 5     | Mooring |
| 0.0048                    | 0.0006   | 0.0048           | 0.0006   | 0            | 0.09    |
|                           |          |                  |          |              |         |

Figure A.2.16 saved simulation Result

## 2.18 EXIT Command

Click **Exit** to close the application.

## MODUSIM MARCO CODE

## Auto-start Command

```

START()
=ADD.MENU(1,L5:M28,9)
=WORKBOOK.ACTIVATE("[MODU.XLW]WELCOM1.XLS")
=RETURN()

```

## Input MODU General Information

```

MDINF()
=DIALOG.BOX(MODUINF)
=RETURN()

```

## Input MODU Location

```

MDLOC()
=FORMULA("=(KDTL-CYMI)*KWDMI/(KDTL-KYMI)",MODUSIM.XLMIJ58)
=FORMULA("=KDTL",MODUSIM.XLMIJ60)

=DIALOG.BOX(MODULOC)
=ACTIVATE("[MODU.XLW]MODUSIM.XLM")
=FORMULA("=(KDTL-CYMI)*KWDMI/(KDTL-KYMI)",IJ58)
=FORMULA("=KDTL",IJ60)

=RETURN()

```

## Input Simulation Pre-setting

```

SIMTYPE()
=DIALOG.BOX(SIMUTYPE)
=RETURN()

```

## Input Simulation Parameter

```

SIMPARA()
=DIALOG.BOX(SIMUPARA)
=RETURN()

```

## Input Random parameter

```

RANDPR()
=DIALOG.BOX(RANDPA)
=RETURN()

```



**Input Correlation between Random Parameter**

**PRCORR()**

```
=DIALOG.BOX(PACORR)
=IF(ALERT("CHANGE CORRELATION PARAMETERS?",1))
= Risk.Correlate(MODUSIM.XLMIB297,1,DPRM,MODUSIM.XLMIB298,1)
= Risk.Correlate(MODUSIM.XLMIB297,1,DPVF,MODUSIM.XLMIB299,1)
= Risk.Correlate(MODUSIM.XLMIB298,1,RMVF,MODUSIM.XLMIB299,1)
=END.IF()
=RETURN()
```

**Input Mooring Capacity**

**MOOR()**

```
=DIALOG.BOX(MOORING)
=RETURN()
```

**Stop by User when in Special Simulation Case**

**STOPP()**

```
=IF(ALERT("STOP SIMULATION?",1))
= HALT()
= WORKBOOK.ACTIVATE("[MODU.XLW]WELCOM1.XLS")
=END.IF()
=RETURN()
```

**Reset the Program**

**MRESET()**

```
=SET.NAME("COLLISIONa",0)
=SET.NAME("COLLISION",0)
=SET.NAME("SIMNUM",0)
=IF(INTYPE=1)
= SET.NAME("XMI",KXMI)
= SET.NAME("YMI",KYMI)
= SET.NAME("WDMI",KWDMI)
= SET.NAME("DTL",KDTL)
=ELSE()
= SET.NAME("XMI",CXMI)
= SET.NAME("YMI",CYMI)
= SET.NAME("WDMI",CWDMI)
= SET.NAME("DTL",CDTL)
=END.IF()
=SET.NAME("XWD", (DTL*WDMI)/(DTL-YMI))
=WORKBOOK.ACTIVATE("[MODU.XLW]WELCOM1.XLS")
=RETURN()
```

Change Active Window to Marco Sheet

**MARCO()**

=FORMULA.GOTO(MODUSIM.XLMIA1)

=RETURN()

Begin the Simulation

**RUN()**

=SET.NAME("COLLISIONa",0)

=SET.NAME("COLLISION",0)

=SET.NAME("SIMNUM",0)

=SET.NAME("Tarcoll1",0)

=SET.NAME("Tarcoll2",0)

=SET.NAME("Tarcoll3",0)

=SET.NAME("Tarcoll4",0)

=SET.NAME("Tarcoll5",0)

=SET.NAME("moorfail",0)

=IF(INTYPE=1)

= SET.NAME("XMI",KXMI)

= SET.NAME("YMI",KYMI)

= SET.NAME("WDMI",KWDMI)

= SET.NAME("DTL",KDTL)

=ELSE()

= SET.NAME("XMI",CXMI)

= SET.NAME("YMI",CYMI)

= SET.NAME("WDMI",CWDMI)

= SET.NAME("DTL",CDTL)

=END.IF()

=SET.NAME("XWD", (DTL\*WDMI)/(DTL-YMI))

=IF(AND(ST=1,STT=2))

= SET.NAME("KKKK",1)

= Risk.Add.Output("B:\[MODU.XLW]MODU.XLS"!\$C\$3:\$D\$6)

= Risk.Simulate(1,50,2,1,0,2,0,0,2,"[modu.xlw]modusim.xmlsimulate",0,0)

=ELSE.IF(AND(ST=1,STT=1))

= SET.NAME("KKKK",SIMM)

= SIMULATE()

= ALERT("SIMULATION FINISHED",3)

=ELSE()

= ACTIVATE("[MODU.XLW]MODU.XLS")

= SELECT("R3C3:R40C6")

= CLEAR(3)

= WORKBOOK.ACTIVATE("[modu.xlw]Route.xlc")

= SET.NAME("KKKK",1)

= SIMULATE()

= DIALOG.BOX(okk)

= WORKBOOK.ACTIVATE("[MODU.XLW]WELCOM1.XLS")

```
=END.IF()  
=RETURN()
```

OK to Return

```
OK()  
= FORMULA.GOTO('B:\[MODU.XLW]WELCOM1.XLS'!A1)  
=RETURN()
```

Simulation Output (Probability of Collision)

Result()

```
=IF(simnum=0)  
=SET.NAME("SIMNUM",1)  
=END.IF()  
  
=IF(ST=1)  
= FORMULA("=SIMNUM",MODUSIM.XLMIJ172)  
=IF(Del)  
= FORMULA("=COLLISION",MODUSIM.XLMIJ174)  
= FORMULA("=COLLISION/SIMNUM",MODUSIM.XLMIJ176)  
=ELSE()  
= FORMULA("=COLLISIONa",MODUSIM.XLMIJ174)  
= FORMULA("=COLLISIONa/SIMNUM",MODUSIM.XLMIJ176)  
=END.IF()  
  
= DIALOG.BOX(DRESULT)  
=ELSE()  
= Route()  
=END.IF()  
=RETURN()
```

Simulation Output (Target Collision Probability)

Resutar()

```
= FORMULA("=Tarcoll1/SIMNUM",MODUSIM.XLMIJ242)  
= FORMULA("=Tarcoll2/SIMNUM",MODUSIM.XLMIJ244)  
= FORMULA("=Tarcoll3/SIMNUM",MODUSIM.XLMIJ246)  
= FORMULA("=Tarcoll4/SIMNUM",MODUSIM.XLMIJ248)  
= FORMULA("=Tarcoll5/SIMNUM",MODUSIM.XLMIJ250)  
= FORMULA("=moorfai",MODUSIM.XLMIJ254)  
= FORMULA("=collision",MODUSIM.XLMIJ256)  
  
=DIALOG.BOX(Tarprop)  
=RETURN()
```

### Draw the MODU Moving Route

**Route()**

```
=WORKBOOK.ACTIVATE("[modu.xlw]Route.xls")

=EDIT.SERIES(1,"Moving Route",'B:\[MODU.XLW]MODU.XLS'!$C$3:$C$40,)
'C:\MODUSIM\[MODU.XLW]MODU.XLS'!$D$3:$D$40,,1)
=EDIT.SERIES(2,"Hurricane Center",'B:\[MODU.XLW]MODU.XLS'!$E$3:$E$40,)
'C:\MODUSIM\[MODU.XLW]MODU.XLS'!$F$3:$F$40,,1)
=DIALOG.BOX(okk)
= WORKBOOK.ACTIVATE("[MODU.XLW]WELCOM1.XLS")
=RETURN()
```

### Save the Simulation Result

**SAVE()**

```
=FORMULA("=[modu.xlw]modusim.xml!moduname",'B:\[MODU.XLW]RESULT.XLS'!D6)

=IF(INTYPE=1)
= FORMULA("=[modu.xlw]modusim.xml!KXMI",'B:\[MODU.XLW]RESULT.XLS'!B10)
= FORMULA("=[modu.xlw]modusim.xml!KYMI",'B:\[MODU.XLW]RESULT.XLS'!C10)
=ELSE()
= FORMULA("=[modu.xlw]modusim.xml!CXMI",'B:\[MODU.XLW]RESULT.XLS'!B10)
= FORMULA("=[modu.xlw]modusim.xml!CYMI",'B:\[MODU.XLW]RESULT.XLS'!C10)
=END.IF()

=FORMULA("=[modu.xlw]modusim.xml!IMMV",'B:\[MODU.XLW]RESULT.XLS'!D10)
=FORMULA("=[modu.xlw]modusim.xml!IMSTD",'B:\[MODU.XLW]RESULT.XLS'!E10)
=FORMULA("=[modu.xlw]modusim.xml!INOM",'B:\[MODU.XLW]RESULT.XLS'!F10)
=FORMULA("=[modu.xlw]modusim.xml!INOB",'B:\[MODU.XLW]RESULT.XLS'!G10)
=FORMULA("=[modu.xlw]modusim.xml!IProb",'B:\[MODU.XLW]RESULT.XLS'!E12)

=FORMULA("=[modu.xlw]modusim.xml!ITar1",'B:\[MODU.XLW]RESULT.XLS'!B14)
=FORMULA("=[modu.xlw]modusim.xml!ITar2",'B:\[MODU.XLW]RESULT.XLS'!C14)
=FORMULA("=[modu.xlw]modusim.xml!ITar3",'B:\[MODU.XLW]RESULT.XLS'!D14)
=FORMULA("=[modu.xlw]modusim.xml!ITar4",'B:\[MODU.XLW]RESULT.XLS'!E14)
=FORMULA("=[modu.xlw]modusim.xml!ITar5",'B:\[MODU.XLW]RESULT.XLS'!F14)

=FORMULA("=[modu.xlw]modusim.xml!Imofail/[modu.xlw]modusim.xml!kkkk",)
'C:\MODUSIM\[MODU.XLW]RESULT.XLS'!G14)
=WORKBOOK.COPY("[modu.xlw]result.xls","result.xlw",1)
=WORKBOOK.ACTIVATE("[modu.xlw]result.xls")

=RETURN()
```

Input the MODU Initial Location from Chart

**LOCHART**

```
=WORKBOOK.ACTIVATE("[modu.xlw]Route.xls")
=IF(INTYPE=1)
= EDIT.SERIES(2,"MODU LOCATION",MODUSIM.XLMI$J$51:$J$51,MODUSIM.XLMI#REF1,,2)
= DIALOG.BOX(okk)
= WORKBOOK.ACTIVATE("[MODU.XLW]WELCOM1.XLS")

=ELSE.IF(INTYPE=2)
= EDIT.SERIES(2,"MODU LOCATION",MODUSIM.XLMI$J$54:$J$54,MODUSIM.XLMI$J$56:$J$56,,2)
=END.IF()
=RETURN()
```

Quit the Program

**EXIT**

```
=DELETE.MENU(1,9)
=CLOSE.ALL()
=RETURN()
```

Main Simulation Code

**SIMULATE**

```
=SET.NAME("DT",DTT*0.5)

=FOR("SS",1,KKKK)
=SET.NAME("mor",0)

=IF(ST=1)
= SET.NAME("PN",RiskPoisson(PNLAM))
=ELSE()
= SET.NAME("PN",1)
=END.IF()

=FOR("N",1,PN)

=IF(OR(STT=2,ST=2))
=ACTIVATE("[MODU.XLW]MODU.XLS")
=SELECT("R3C3:R40C4")
=CLEAR(3)
=END.IF()

=SET.NAME("COLL",0)
=SET.NAME("STOP",0)
=SET.NAME("XM",XMI)
=SET.NAME("YM",YMI)
```

```

=SET.VALUE(REPORT,1)
=SET.VALUE(CONT,1)

=IF(ST=1)
= SET.NAME("XO",RiskUniform(XOMIN,XOMAX))
= SET.NAME("FI",RiskTriang(FIMIN,FILIKE,FIMAX)*PI()/180)
= SET.NAME("DP",RiskLognorm(DPMEAN,DPSTD))
= SET.NAME("RM",RiskLognorm(RMMEAN,RMSTD))
= SET.NAME("VF",RiskLognorm(VFMEAN,VFSTD))
= SET.NAME("MMV",RiskLognorm(IMMV,MSTD)*1000)

=ELSE()
= SET.NAME("XO",SXO)
= SET.NAME("FI",SFI*PI()/180)
= SET.NAME("DP",SDP)
= SET.NAME("RM",SRM)
= SET.NAME("VF",SVF)
= SET.NAME("MMV",IMMV*1000)
=END.IF()

=IF(ABS(FI-PI()/2)<0.001)
= IF(ABS(XM-XO)>(10*RM))
= SET.NAME("XH",1000)
= ELSE()
= SET.NAME("XH",XO)
= SET.NAME("YH",YM-SQRT((10*RM)^2-(XM-XO)^2))
= END.IF()
=ELSE.IF(FI<>(PI()/2))
= SET.NAME("XH",FUNXH(XM,YM,FI,XO,RM))
= SET.NAME("YH",TAN(FI)*(XH-XO))
=END.IF()

=IF(XH=1000,GOTO(NEXT))

=SET.NAME("KK",0)
=SUBTOTFOR()
=IF(OR(YH>DTL,YM>DTL,NDR>11,DR>(WDM+SUR+HM/2)),GOTO(NEXT))

=WHILE((TOTALF-MMV)<0)

=SET.NAME("XH",XH+VF*DT*COS(FI))
=SET.NAME("YH",YH+VF*DT*SIN(FI))
=IF(OR(YH>DTL,YM>DTL,NDR>11,DR>(WDM+SUR+HM/2)),GOTO(NEXT))

=SET.NAME("KK",0)
=SUBTOTFOR()

=IF(OR(YH>DTL,YM>DTL,NDR>11,DR>(WDM+SUR+HM/2)),GOTO(NEXT))

```

```

=NEXT()

=IF(mor=0)
=SET.NAME("moorfail",moorfail+1)
=SET.NAME("mor",1)
=END.IF()

=FOR("NN",1,10000)

=IF(OR(ST=2,STT=2))
=SUBWRITE()
=END.IF()

=IF(VM<>0)
=SUBCOLLISION()
=ELSE()
=SET.NAME("COLL",0)
=END.IF()

=IF(AND(ST=1,COLL=1),GOTO(nextt))
=IF(AND(ST=2,STOP=1),GOTO(nextt))
=IF(OR(YH>DTL,YM>DTL,NDR>11,DR>(WDM+SUR+HM/2)),GOTO(NEXT))

=SET.NAME("XH",XH+VF*DT*COS(FI))
=SET.NAME("YH",YH+VF*DT*SIN(FI))

=SET.NAME("XM",XM+VM*DT*COS(WD))
=SET.NAME("YM",YM+VM*DT*SIN(WD))

=SET.NAME("KK",1)
=SUBTOTFOR()

=NEXT()

=NEXT()

=SET.NAME("simnum",simnum+1)

=IF(OR(ST=2,STT=2))
=ACTIVATE("[MODU.XLW]MODU.XLS")
=SELECT("r3c3:r40c6")
=COPY()
=PASTE.SPECIAL(3,1,FALSE,FALSE)
=END.IF()

=NEXT()

=RETURN()

```

# Environment Force Calculation

## SUBTOTFOR()

```

=SET.NAME("CTA",FUNCTA(XM,YM,XH,YH,FI))
=SET.NAME("NDR",FUNNDR(XM,YM,XH,YH,RM))

=IF(NDR>11,RETURN())

=SET.NAME("W",FUNWINSPEE(DP,RM,VF,CTA,NDR))
=SET.NAME("WD",FUNWINDIR(CTA))
=SET.NAME("WDM",FUNWDM(WDM,YMI,YM,DTL))
=SET.NAME("CV",FUNCURVEL(W,WDM))
=SET.NAME("HM",FUNWAVHEI(W,WDM))
=SET.NAME("T",FUNPERIOD(W,CTA))
=SET.NAME("SUR",FUNSURGE(HM,WDM))

=SET.NAME("CUF",FUNCURFOR(PARACUR,DR,SUR,CV,DCC,DCE,LPO,HPO,CUD))
=SET.NAME("WINF",FUNWINFOR(PARAWIN,W,EWA))
=SET.NAME("WAVDF",FUNWAVDRI(HM))

=SET.NAME("WAF",FUNWAVFOR(PARAWAV,DR,SUR,HM,T,WDM,DCC,DCE,LPO,HPO,WPO))
=SET.NAME("TOTALF",WAF+WINF+CUF+WAVDF)

=IF(KK=1,GOTO(KKK))
=IF(TOTALF<MMV)
= RETURN()
=END.IF()

=IF(DR>(WDM+SUR))

= IF(NOM=NOB)
= SET.NAME("ACCE",TOTALF*9.8/2.2/(1000*DISP))
= SET.NAME("VM",0.5*ACCE*T/4*1.944)
= ELSE.IF(NOM<>NOB)
= SET.NAME("DRAGF",2*DMP*MMV*(NOM-NOB)/NOM)
= IF(TOTALF<DRAGF)
= SET.NAME("VM",0)
= ELSE.IF(TOTALF>DRAGF)
= SET.NAME("ACCE",(TOTALF-DRAGF)*9.8/2.2/(1000*DISP))
= SET.NAME("VM",0.5*ACCE*T/4*1.944)
= END.IF()
= END.IF()

=ELSE.IF(DR<(WDM+SUR))

= IF(NOM=NOB)

```



```

= IF(CUD=1)
=   SET.NAME("VM",SQRT((WINF+WAVDF)/(2.85*((4*DCC+DCE)*(DR+SUR)*0.7+2*LPO*HPO))))
=   +CV)
= ELSE.IF(CUD=2)
=   SET.NAME("VM",SQRT((WINF+WAVDF)/(2.85*((4*DCC+DCE)*(DR+SUR)*0.7+2*LPO*HPO))))
=   +CV*0.75)
= ELSE.IF(CUD=3)
=   SET.NAME("VM",SQRT((WINF+WAVDF)/(2.85*((4*DCC+DCE)*(DR+SUR)*0.7+2*LPO*HPO))))
=   +CV*0.5)
= END.IF()

= ELSE.IF(NOM<>NOB)

=   SET.NAME("DRAGF",2*DMP*MMV*(NOM-NOB)/NOM)
=   IF((WAVDF+WINF+CUF)<DRAGF)
=     SET.NAME("VM",0)
=     RETURN()
=   END.IF()

=   IF((WINF+WAVDF)>DRAGF)
=     IF(CUD=1)
=       SET.NAME("VM",SQRT((WINF+WAVDF-DRAGF)/(PARACUR*2.85*((4*DCC+DCE)
=       *(DR+SUR)*0.7+2*LPO*HPO))))+CV)
=     ELSE.IF(CUD=2)
=       SET.NAME("VM",SQRT((WINF+WAVDF-DRAGF)/(PARACUR*2.85*((4*DCC+DCE)
=       *(DR+SUR)*0.7+2*LPO*HPO))))+CV*0.75)
=     ELSE.IF(CUD=3)
=       SET.NAME("VM",SQRT((WINF+WAVDF-DRAGF)/(PARACUR*2.85*((4*DCC+DCE)
=       *(DR+SUR)*0.7+2*LPO*HPO))))+CV*0.5)
=     END.IF()
=   ELSE.IF((WINF+WAVDF)<DRAGF)
=     IF(CUD=1)
=       SET.NAME("VM",CV-SQRT((DRAGF-WINF-WAVDF)/(PARACUR*2.85*((4*DCC+DCE)
=       *(DR+SUR)*0.7+2*LPO*HPO))))
=     ELSE.IF(CUD=2)
=       SET.NAME("VM",CV*0.75-SQRT((DRAGF-WINF-WAVDF)/(PARACUR*2.85*((4*DCC+DCE)
=       *(DR+SUR)*0.7+2*LPO*HPO))))
=     ELSE.IF(CUD=3)
=       SET.NAME("VM",CV*0.5-SQRT((DRAGF-WINF-WAVDF)/(PARACUR*2.85*((4*DCC+DCE)
=       *(DR+SUR)*0.7+2*LPO*HPO))))
=     END.IF()
=   END.IF()

= END.IF()

=END.IF()

=IF(VM<0)
=  ALERT("VM < 0",3)

```

```
= HALT()
=END.IF()

=RETURN()
```

#### Check for Collision Happen

##### SUBCOLLISION()

```
=SET.NAME("XX1",XM)
=SET.NAME("YY1",YM)
=SET.NAME("XX2",XM+VM*DT*COS(WD))
=SET.NAME("YY2",YM+VM*DT*SIN(WD))
=ACTIVATE("[MODU.XLW]MODU.XLS")
=EXTRACT(TRUE)

=IF('B:\[MODU.XLW]MODU.XLS'!end<>"SAFE")

= SET.NAME("pc",'B:\[MODU.XLW]MODU.XLS'!Ppc)
= SET.NAME("COLLISIONa",COLLISIONa+1)
= SET.NAME("COLLISION",COLLISION+pc)
= SET.NAME("COLL",1)

= IF(AND(Spe,'B:\[MODU.XLW]MODU.XLS'!spec="TAR"))
=   SET.NAME("spnum",'B:\[MODU.XLW]MODU.XLS'!Tarnum)
=   SPECTAR()
=   END.IF()

=   IF(AND(REPORT=1,ST=2))
=     DIALOG.BOX(COLLHAPP)
=     IF(CONT<>1)
=       SET.NAME("stop",1)
=     END.IF()
=   END.IF()

=ELSE.IF('B:\[MODU.XLW]MODU.XLS'!end="SAFE")
= SET.NAME("COLL",0)
=ELSE()
= ALERT("DATABASE ERROR",3)
= HALT()
=END.IF()

=RETURN()
```

#### Record Spectial Target Collision Number

##### **SPECTAR()**

```
=IF(spnum=1)
= SET.NAME("Tarcoll1",Tarcoll1+pc)
=ELSE.IF(spnum=2)
= SET.NAME("Tarcoll2",Tarcoll2+pc)
=ELSE.IF(spnum=3)
= SET.NAME("Tarcoll3",Tarcoll3+pc)
=ELSE.IF(spnum=4)
= SET.NAME("Tarcoll4",Tarcoll4+pc)
=ELSE.IF(spnum=5)
= SET.NAME("Tarcoll5",Tarcoll5+pc)
=END.IF()
=RETURN()
```

#### Functions of Force calculation

##### **FUNCTA**

```
=RESULT(1)
=ARGUMENT("XMF",1)
=ARGUMENT("YMF",1)
=ARGUMENT("XHF",1)
=ARGUMENT("YHF",1)
=ARGUMENT("FIF",1)
=IF(ABS(XMF-XHF)<0.001)
= IF(YHF>YMF)
= SET.NAME("CTAF",2*PI()-FIF)
= ELSE()
= SET.NAME("CTAF",PI()-FIF)
= END.IF()
=ELSE()
= SET.NAME("KF",ATAN((YHF-YMF)/(XHF-XMF)))
= IF(XHF>XMF)
= SET.NAME("CTAF",1.5*PI()+KF-FIF)
= ELSE()
= SET.NAME("CTAF",PI()/2+KF-FIF)
= END.IF()
=END.IF()
=RETURN(CTAF)
```

##### **FUNNDR**

```
=RESULT(1)
=ARGUMENT("XMF",1)
=ARGUMENT("YMF",1)
=ARGUMENT("XHF",1)
=ARGUMENT("YHF",1)
```

```

=ARGUMENT("RMF",1)
=SET.NAME("NDRF",SQRT((XMF-XHF)^2+(YMF-YHF)^2)/RMF)
=RETURN(NDRF)

```

#### FUNWINSPEE

```

=RESULT(1)
=ARGUMENT("DPF",1)
=ARGUMENT("RMF",1)
=ARGUMENT("VFF",1)
=ARGUMENT("CTAF",1)
=ARGUMENT("NDRF",1)
=SET.NAME("WMF",0.885*(5.6*SQRT(DPF)-0.125*RMF)+VFF*COS(CTAF))
=IF(NDRF>1)
= SET.NAME("WF",1.944*WMF*NDRF^(-0.38+0.08*COS(CTAF)))
=ELSE()
= SET.NAME("WF",1.944*1.047*WMF*(1-EXP(-3.1*NDRF)))
=END.IF()
=RETURN(WF)

```

#### FUNWINDIR

```

=RESULT(1)
=ARGUMENT("CTAF",1)
=SET.NAME("WDF",CTAF+(22+10*COS(CTAF))*PI()/180+PI()/2)
=RETURN(WDF)

```

#### FUNCURVEL

```

=RESULT(1)
=ARGUMENT("WF",1)
=ARGUMENT("WDMF",1)
=SET.NAME("SECF",2.5-1.5/XWD*WDMF)
=SET.NAME("CVF",0.025*WF*SECF)
=RETURN(CVF)

```

#### FUNWAVHEI

```

=RESULT(1)
=ARGUMENT("WF",1)
=ARGUMENT("WDMF",1)
=SET.NAME("SEWF",-0.4*(WDMF/XWD)^2+0.9*(WDMF/XWD)+0.5)
=SET.NAME("HMF",1.73*0.25*3.3*WF/1.944*SEWF)
=IF(HMF>0.6*WDMF)
= SET.NAME("HMF",0.6*WDMF)
=END.IF()
=RETURN(HMF)

```

**FUNPERIOD**

```
=RESULT(1)
=ARGUMENT("WF",1)
=ARGUMENT("CTAF",1)
=SET.NAME("A1F",8-3.5*COS(CTAF)+2.7*SIN(CTAF))
=SET.NAME("A2F",0.143+0.138*COS(CTAF)-0.074*SIN(CTAF))
=SET.NAME("TF",A1F*WF^A2F)
=RETURN(TF)
```

**FUNSURGE**

```
=RESULT(1)
=ARGUMENT("HMF",1)
=ARGUMENT("WDMF",1)
=SET.NAME("SURF",0.03*HMF*(1+3*(XWD-WDMF)/XWD))
=RETURN(SURF)
```

**FUNCURFOR**

```
=RESULT(1)
=ARGUMENT("PARACURF",1)
=ARGUMENT("DRF",1)
=ARGUMENT("SURF",1)
=ARGUMENT("CVF",1)
=ARGUMENT("DCCF",1)
=ARGUMENT("DCEF",1)
=ARGUMENT("LPOF",1)
=ARGUMENT("HPOF",1)
=ARGUMENT("CUDF",1)
=IF(CUDF=1)
= SET.NAME("CUFF",PARACURF*2.85*((4*DCCF+DCEF)*(DRF+SURF)*0.7+2*LPOF*HPOF)*CVF^2)
=ELSE.IF(CUDF=2)
= SET.NAME("CUFF",PARACURF*2.85*((4*DCCF+DCEF)*(DRF+SURF)*0.7*0.75^2
+2*LPOF*HPOF*0.5^2)*CVF^2)
=ELSE.IF(CUDF=3)
= SET.NAME("CUFF",PARACURF*2.85*((4*DCCF+DCEF)*(DRF+SURF)*0.7*0.5^2)*CVF^2)
=ELSE()
=HALT()
=END.IF()
=RETURN(CUFF)
```

**FUNWAVFOR**

```
=RESULT(1)
=ARGUMENT("PARAWAVF",1)
=ARGUMENT("DRF",1)
=ARGUMENT("SURF",1)
```

```

=ARGUMENT("HMF",1)
=ARGUMENT("TF",1)
=ARGUMENT("WDMF",1)
=ARGUMENT("DCCF",1)
=ARGUMENT("DCEF",1)
=ARGUMENT("LPOF",1)
=ARGUMENT("HPOF",1)
=ARGUMENT("WPOF",1)
=SET.NAME("LF",5.12*TF^2*SQRT(TANH(2*PI()*WDMF/(5.12*TF^2))))
=SET.NAME("WA1F",32*HMF*PI()/LF*0.25)
=IF((WDMF-DRF)>0)
=SET.NAME("WA2F",WA1F*COSH(2*PI()*(WDMF-DRF)/LF)/COSH(2*PI()*WDMF/LF))
=ELSE()
=SET.NAME("WA2F",WA1F/COSH(2*PI()*WDMF/LF))
=END.IF()
=SET.NAME("WAaF",(WA1F+WA2F)/2)
=SET.NAME("WAF1F",PARAWAVE*2*PI()/4*(4*DCCF^2+DCEF^2)*(DRF+SURF+HMF/2)*WAaF)
=SET.NAME("WAF2F",PARAWAVE*2*LPOF*HPOF*WPOF*WA2F)
=SET.NAME("WAFF",WAF1F+WAF2F)
=RETURN(WAFF)

```

#### **FUNWINFOR**

```

=RESULT(1)
=ARGUMENT("PARAWINF",1)
=ARGUMENT("WF",1)
=ARGUMENT("EWAFF",1)
=SET.NAME("WINFF",PARAWINF*0.0034*EWAFF*WF^2)
=RETURN(WINFF)

```

#### **FUNWAVDRI**

```

=RESULT(1)
=ARGUMENT("HMF",1)
=IF(HMF>2)
=SET.NAME("WAVDFF",45000/28*HMF/1.73-5000/4)
=ELSE()
=SET.NAME("WAVDFF",0)
=END.IF()
=RETURN(WAVDFF)

```

#### **FUNXH**

```

=RESULT(1)
=ARGUMENT("XMF",1)
=ARGUMENT("YMF",1)
=ARGUMENT("FIF",1)
=ARGUMENT("XOF",1)
=ARGUMENT("RMF",1)

```

```

=SET.NAME("D1F",ABS(TAN(FIF)*XMF-YMF-XOF*TAN(FIF))/SQRT(TAN(FIF)^2+1))
=SET.NAME("D2F",SQRT(XMF^2+(YMF+XOF*TAN(FIF))^2))

=IF(D1F>(10*RMF))
=SET.NAME("XHF",1000)
=RETURN(XHF)
=END.IF()

=IF(FIF<(PI()/2))
=SET.NAME("XHF",SQRT((10*RMF)^2-D1F^2)-SQRT(D2F^2-D1F^2))*(-COS(FIF)))
=ELSE()
=SET.NAME("XHF",SQRT((10*RMF)^2-D1F^2)+SQRT(D2F^2-D1F^2))*(-COS(FIF)))
=END.IF()

=RETURN(XHF)

```

#### **FUNWDM**

```

=RESULT(1)
=ARGUMENT("WDMIF",1)
=ARGUMENT("YMIF",1)
=ARGUMENT("YMF",1)
=ARGUMENT("DTLF",1)
=SET.NAME("WDMF",DTLF-YMF)*WDMIF/(DTLF-YMIF)
=RETURN(WDMF)

```

#### **SUBWRITE()**

```

=ACTIVATE("[MODU.XLW]MODU.XLS")
=SELECT(I$C$1)
=SELECT.END(4)
=SELECT(OFFSET(SELECTION(),1,0))
=FORMULA("=[MODU.XLW]MODUSIM.XLMIXM",SELECTION())
=SELECT(OFFSET(SELECTION(),0,1))
=FORMULA("=[MODU.XLW]MODUSIM.XLMIYM",SELECTION())
=SELECT(OFFSET(SELECTION(),0,1))
=FORMULA("=[MODU.XLW]MODUSIM.XLMIXH",SELECTION())
=SELECT(OFFSET(SELECTION(),0,1))
=FORMULA("=[MODU.XLW]MODUSIM.XLMIYH",SELECTION())
=RETURN()

```

Calculate Probability of Collision within the Target Circle

#### **LARGEPI()**

```

=SET.NAME("cc",0)
=FOR("I",1,200)
=SET.NAME("xox",RiskUniform(-RF,RF))
=SET.NAME("FIH",RiskUniform(0,180)*PI()/180)

```

```

=FOR("II",1,NM)
=SET.NAME("xf",RiskUniform(-RF,RF))
=SET.NAME("yf",RiskUniform(-RF,RF))

=IF(xf^2+yf^2-RF^2>0)
=  GOTO(PP)
=END.IF()

=IF((FIH-PI()/2)<0.001)
=  SET.NAME("dd",ABS(xox-xf))
=ELSE.IF(OR(FIH=0,(FIH-PI()/2)<0.001))
=  SET.NAME("dd",ABS(xox-yf))
=ELSE()
=  SET.NAME("dd",ABS(TAN(FIH)*xf-yf-TAN(FIH)*xox)/SQRT(TAN(FIH^2)+1))
=END.IF()

=IF(dd<RS)
=  SET.NAME("cc",cc+1)
=  GOTO(PPP)
=END.IF()

=NEXT()
=NEXT()
=FORMULA("=CC/200",MODUSIM.XLMIJ645)
=ALERT("Simulation Finished!",3)
=DIALOG.BOX(LPRESU)
=RETURN()

```

Input Target Circle Information

FINFO()

=DIALOG.BOX(INFO)

=RETURN()